BESSEMER CENTENARY CELEBRATIONS, 1956

British Association for the Advancement of Science

Steelmaking Since Bessemer

By Sir Charles Goodeve, O.B.E., D.Sc., F.R.S.

THE BRITISH ASSOCIATION has a long history of contributions to the 'advancement of science.' It is justifiably most proud of the fact that its summer meeting exactly one hundred years ago was chosen as the place to announce a discovery which was to have an effect upon civilization ranking amongst the most important in the history of mankind. At Cheltenham on 11th August, 1856, Mr. Henry Bessemer told of a new method of making steel, a method which was, at least in principle, extremely simple and cheap. This exciting announcement was fully reported in *The Times* a few days later.

The speed with which Bessemer, working at St. Pancras almost alone, brought about the original successes which led to his announcement; the awful setback and disappointment which followed when he tried to make the process work in the steelworks of his licensees; the even harder work, now with the help of some others, which finally won through to ultimate success—all add up to a classic which is a prototype for the story of many inventions. Bessemer had already achieved financial independence through his invention of a method for making bronze powder for gold paint, and one which was very much cheaper than the existing methods. He took advantage of this independence to press forward with his experiments at a fast rate. Bessemer was a determined and courageous man, and the setback only spurred him on through the usual frustrating period of bringing a new discovery into commercial use. His story has set an example and given courage to many inventors.

Much has been said in this centenary year[1–3] about the discovery itself, the developments which followed, and the revolutionary consequences of the introduction of tonnage steel. I propose to talk about the chemistry of this high-temperature process, and in particular about that chain of chemical development which was started by Bessemer and indeed has not yet finished. I refer to the making of steel by pneumatic processes.

Steelmaking, because of its importance, has led the way through most of the last hundred years in technical progress in high-temperature chemistry. In recent years, however, processes to make metals such as titanium, which require still higher temperatures, are sharing this leading position.

Let me recall for you the chemical problem faced by steelmakers today, a problem which is much the same as that faced by Bessemer. Iron ore is essentially burnt iron or iron oxide, mixed with oxides of other metals, principally silicon, aluminium, and calcium. The first stage is to 'un-burn' the iron or deoxidize it to form the metal, which, being heavier and insoluble in the remaining oxides, will, if hot enough to be molten, separate from the other components. However, in doing this, one has to deoxidize selectively to make sure that one does not bring into the metal a large number of impurities. Fortunately this can readily be done, so that little of the silicon, and none of the calcium and aluminium, comes into the metallic state. However, one cannot prevent all the phosphorus and some sulphur commonly present in the ore and in the fuel respectively, coming into the metal.

Presidential Address to Section B (Chemistry) of the British Association for the Advancement of Science, delivered at the Association's Meeting in Sheffield on 30th August, 1956. The Address is reprinted by kind permission of the Editor of *The Advancement of Science*.

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A cheap and simple deoxidizing agent is carbon in the form of coke, and this when mixed with iron ore in the blast-furnace carries out the necessary reduction very efficiently and rapidly. It is not practicable to stop the process of deoxidation at the right place, and the metal which comes out of the blast-furnace is over-deoxidized and contains a large quantity of carbon. This amounts to only about 4% by weight, but represents nearly 16% of the atoms in the metal. This iron–carbon alloy corresponds to a stable chemical stage in the process and, therefore, one which is exceedingly difficult to avoid, if carbon is used. It does, however, present other problems and these are the problems facing the steelmaker himself.

Once liquid pig iron is made the problem is to reoxidize it to remove the carbon and possibly other impurities. Before the days of Henry Bessemer this was done by rabbling or stirring with molten iron oxides in what is called a puddling furnace. This process, which is still carried on today in some remote parts of England (!), operates in three main stages. The first of these is one of the oldest purification processes known to chemists, that of crystallization. To understand this, I must remind you that pure iron crystallizes at a temperature of 1535° C. The melting point of pig iron, on the other hand, is reduced by the presence of the carbon and other impurities to somewhere near 1100° C. The puddling furnace operates at a temperature just above this. When half the carbon has been removed by oxidation through reaction with the iron oxides, iron crystals begin to form, and these are, like most crystals, purer than the melt from which they have come.

However, they still contain more than 1% carbon and this is removed in a second stage. The crystals are stirred with the molten oxide slag so that the carbon, on diffusing to the surface of the crystals, is oxidized and boils off. Very low carbon contents can be obtained in this way.

The final stage consists of raising the temperature and forming a ball of iron crystals, with some entrapped slag, on the end of a rabbling rod. These crystals cannot be separated by gravity as a liquid iron does in the blast-furnace, but a partial separation from the slag can be achieved by skilful squeezing under a hammer.

The process requires great skill and is an extremely slow and arduous one. Two to three hours are required to produce ¼ ton of metal. The first stage is limited by the difficulty in stirring rapidly enough to promote a chemical reaction between a viscous slag and a heavier molten metal beneath it, and the second stage depends on diffusion in the solid metal phase. There are important physical limitations as well, especially in the third stage of slag removal under a hammer. The iron itself, known to you all as ' wrought ' iron, has some good qualities, but is much inferior to modern steel.

The open-hearth furnace, which was invented shortly after Bessemer's converter, operates in a way similar to the first stage of a puddling furnace in that a slag containing iron oxide must react with a bath of melted steel scrap to which has been added liquid or cold pig iron. However, the chemical reaction in the open-hearth furnace is much faster than that in the puddling furnace because it operates at a temperature nearly 400° C higher. Hand stirring is now impossible, but the carbon monoxide gas evolved comes off fast enough to give a reasonable stirring action, and the oxidation of many tons of metal is brought to completion in a matter of 5–6 hours. A modern large open-hearth furnace will produce a ton of steel every 3 minutes.

We can now have a look at what Bessemer did. Instead of supplying the oxygen in the form of iron oxide, he decided to use the very simple and cheap method of blowing air through the metal itself. The cost of his oxygen was therefore only that of running his pump. It must have taken a great deal of courage and skill to have tried such a thing with the equipment available at that time. The speed of his process was limited only by the fact that too great an air flow might blow the iron out of the top of his converter. The chemical reaction was now extremely fast, about a thousand times faster than the puddling furnace of that day. Indeed, a modern Bessemer vessel one-tenth the size of a modern open-hearth furnace can convert 8 tons of iron or steel in the 3 minutes that the open-hearth takes to convert 1 ton.

We do not have to look far for the cause of this tremendous difference. We now know that at steelmaking temperatures, where the molecules move at high velocities, a good proportion of the collisions between potentially reactive molecules are successful simply because these collisions occur with great force, a force sufficient to overcome the resistance to chemical change caused by the stability of the original molecules. In the language of physical chemistry, a reasonable proportion of the colliding molecules have the required ' energy of activation.' The rates of iron- and steelmaking reactions are therefore governed by the rates at which collisions between the right kind of molecules occur, and this in turn is governed by diffusion and by the rate of mixing. We will see presently, however, that there is at least one exception to this rule.

Henry Bessemer was an engineer, and while spotting that his fuel could be found in the carbon in the iron, he appreciated the importance of mixing, and that was the basic cause of his triumph. He knew that he had to disperse his air in fine bubbles in the molten metal to give a large area of gas/metal interface and to agitate the mixture violently.

However, Bessemer could not get out of his difficulties because he was not a physical chemist. One could hardly blame him for that because the breed was not known at that time, despite the extensive hybridization of scientists that had already taken place.

What went wrong with the Bessemer process immediately after the announcement? The steel made in his experimental work at St. Pancras was perfectly alright, but steel made anywhere else was useless. It was soon found that, by a lucky chance, the pig iron from which the first Bessemer steel was made was very low in phosphorus. The pig iron that other people tried to use contained more phosphorus, and this remained in the final steel and rendered it unworkable.

The laws of nature, together with thermodynamic data, now well known to physical chemists, indicate that oxides of phosphorus are more readily reduced than those of iron. Hence, all of the phosphorus originally in the iron ores comes out in the pig iron from the blast-furnace. Selective deoxidation works against the ironmaker here because the phosphorus is deoxidized before or at the same time as the iron. From the very same rules one might deduce that selective *oxidation* cannot help because the iron will oxidize before the phosphorus. Indeed, Bessemer blew and blew his phosphorus-containing iron, burning half of it away without making any impression on the phosphorus. He finally gave up trying and confined his process to iron produced from very low-phosphorus ore. Fortunately, there was such an ore in Cumberland and the process operated successfully there, and it still does until this day. In the United States there are great deposits of low-phosphorus iron ores, and accordingly the process got away to a very good start in that country. Indeed, the great railway expansion that took place nearly a hundred years ago owes itself entirely to the Bessemer process. Bessemer's first iron came from the low-phosphorus ores of Sweden, and that country played a major part in the development of the process.

It was left to a young chemist with a good scientific training, Sidney Gilchrist Thomas, to find the solution to Bessemer's phosphorus problems twenty years later. I have spoken about selectivity rules governing oxidation and deoxidation as if they were quite simple, but indeed they are not. In recent years a tremendous amount of research work has been done to put these on to a quantitative basis. Let me attempt to outline these rules in modern terms. Every element or compound when present in a phase such as liquid metal has a potential, that is, a ' chemical potential.' If an element likes to be in a particular phase, that is, it has an attraction for its intimate surroundings, its potential will be low. If, however, it has little liking for its surroundings, then its potential will be relatively high. This chemical potential can be measured by the vapour pressure, p, of the element or compound, and indeed is given by the quantity $RT \log p$. Scientists will recognize that this term has the dimensions of work or energy and they know that electrical potential can also be measured in units of work.

In all steelmaking systems we have to deal with three phases, a metal phase, a gaseous phase, and what is probably best simply called a slag phase, the latter consisting of a mixture of inorganic compounds such as silica, lime, and iron oxide. An element such as oxygen or phosphorus can be present in all three phases and will have a potential in each of these depending on its concentration and on its attraction for the other elements and compounds which are present. The potential of an element rises logarithmically as its concentration rises, and falls with an increase in attraction, as measured by the heat evolved on entering the phase.

The fundamental second law of thermodynamics tells us that an element can only move on its own from a phase of higher potential to one of lower potential. This is parallel to the simple axiom that water can run only down a hill. We have through this law a means of determining the direction of a chemical reaction. If we want to remove an element such as phosphorus from a metal phase, then we can either raise its potential in that phase or lower its potential in the other phases with which the metal is in contact. We can in fact raise the phosphorus potential in metals but only very slightly, and, indeed, little use can be made of this effect. We know that in practice we cannot lower the potential of phosphorus in the gaseous phase sufficiently. Therefore, we are left with only one thing we can do, and that is to lower the phosphorus potential in the slag phase, and in this lies the secret of the Sidney Gilchrist Thomas process. In simpler language, we must not just attempt to push the phosphorus out of the iron but we must draw it out by means of a slag which has a strong affinity either for phosphorus or for a compound of phosphorus such as P_2O_5. We do not know of any inorganic compounds that have a strong affinity for phosphorus in itself, but only of some which have this for the pentoxide. Strongly basic materials such as lime and magnesia have the affinity that we require.

But we can get P_2O_5 only by oxidation. This means that we need a high oxygen potential in the system in order to help the phosphorus in the metal to go over into the slag. This and a highly basic but fluid slag are the primary conditions for phosphorus removal. Under such conditions the ratio of the phosphorus concentration in the slag to that in the metal, known as the equilibrium partition ratio, can be got up as high as 500 (on a weight basis). At this equilibrium, the phosphorus potentials in the slag and metal are equal and the high relative concentration achieved in the slag is a consequence of the low energy level of the phosphorus atoms because of their high attraction towards their surroundings.

The chemistry of this sounds comparatively simple, but the practical problems facing Thomas of making a basic lining to a Bessemer converter were enormous. Nevertheless he, with the help of his Welsh cousin, Percy Gilchrist, solved them, and the improved process swept the world in an even bigger way than the original Bessemer process. Indeed, it rather took the place of the former. It made possible the development of the great French and German iron and steel industries and the industries of Luxembourg and Belgium. It brought the Bessemer process into use with British home ores in the Cleveland and Midland areas and in South Wales, and went into many other parts of the world. Today over 60% of French steel and one half of the German is made by this process. This British invention allowed the industrial revolution to spread to countries in Europe and brought them into severe competition with this country.

Turning back to the chemistry of the process, we find that in the Thomas–Bessemer converter oxidation of the impurities takes place more or less in sequence. The oxygen of the air first attacks the silicon which is always present to some extent in pig iron, and burns this to silica, the oxide of silicon. When this is mostly gone, the oxygen then attacks the carbon, and as the quantity present is rather large, some time

is taken over this. When the carbon is mostly gone, the air will then oxidize the phosphorus if there is lime there to take up the phosphate produced. Some oxidation of iron also takes place during the phase of phosphorus removal.

Indeed, when one looks at the actual mechanism of this reaction, one sees that the oxygen molecules in the air entering the bottom of the molten-iron bath are much more likely to collide with iron atoms. These form iron oxide which subsequently reacts with the silicon and carbon while the bubbles rise. Oxidation of the phosphorus takes place when the iron oxide gets through to the lime to make a liquid slag on top of the bath, and this can occur only when very little carbon is left in the iron.

However, even after Thomas's success in the removal of phosphorus, the ups and downs of pneumatic processes were far from being at an end because a number of handicaps remained. The air blown through the converter contains 79% of nitrogen, which has a considerable solubility in steel, especially when the carbon is reduced. (Carbon pushes up the potential of nitrogen in the metal phase, that is, opposes its entry.) This solubility is only partially achieved in practice, probably because nitrogen is very stable and only a small proportion of its molecules have the required energy of activation to dissolve in the iron. A certain amount of nitrogen in the steel does not matter for rails or tubes, but, unless special steps are taken to lower it, the steel will not be useful for some other purposes. For example, ships cannot be made indiscriminately of such steel otherwise they might break. The weakness of Bessemer steel in this respect was found to be almost entirely absent in the open-hearth process invented by Siemens and Martin. It was some time before the reason for this difference was discovered: the nitrogen content of open-hearth steel was two to three times less than it was in Bessemer steel.

The open-hearth process also has one very important practical advantage, particularly in Great Britain, in that one can, along with pig iron, melt steel scrap very economically and make fresh good steel thereby. Therefore, even though the open-hearth process goes many times more slowly than the Bessemer process, it nevertheless can be more economical where steels are required for a wide variety of uses.

There is a third handicap to the Thomas and Bessemer processes. Enough heat must be generated to raise the temperature of the metal, melt the slag-forming materials, and provide for the high thermal losses in the emitted gases and through the walls of the vessel. This and other operating factors put restrictions on the composition and temperature of the pig iron that can in practice be used; for example, the Thomas process requires an iron high in phosphorus and low in silicon, and the Bessemer process an iron low in phosphorus and high in silicon.

For these reasons, and despite its cheapness and simplicity, the Thomas process steadily gave way to the open-hearth, until today it represents less than 15% of the world's production.

However, the decline is now being arrested, largely through developments made on the Continent. The first of these was the invention by Linde and Fränkl of the regenerator system of producing oxygen from air. This makes possible the large-scale or tonnage production of oxygen and reduces the cost of oxygen gas, but not liquid, by a factor of about five. This has led to a second recent Continental development, the use of this oxygen in the Thomas converter, either by enriching the air with oxygen or by using pure oxygen diluted with steam or with carbon dioxide. The second of these, the oxygen–steam process, was developed in Belgium and is making rapid headway there and also in France and Germany. It is about to do so in this country; there will be two converter plants operating this process by the autumn of this year. In two or three years they will be joined by a third completely new plant.

The use of oxygen in the Thomas–Bessemer process removes most of the difficulties referred to above. First of all the nitrogen content of the steel can be reduced to very low levels. More important, however, is that steelmakers are given a new degree of freedom; they are no longer bound to the 20·8% oxygen in air but can change this at will. This allows scrap to be used and temperature/time paths to be followed which are best suited to the particular raw materials and final product. Oxygen brings back the small and frequent batch which is so much easier to integrate into the other continuous processes of a steelworks. It brings its own problems, of course, but these will, I am sure, yield to the research effort now being put to them.

The Bessemer star is in the ascendant again; how far it will rise this time one cannot foretell. It seems likely that we will see a marked increase in the percentage of low-carbon steel made in this country by the process.

One cannot give a discourse on pneumatic steelmaking methods without bringing in a rather healthy young child which was born in Austria. The Thomas and Bessemer processes are almost too fast, and as a consequence it is difficult to control the composition to the required final specification. Part of the trouble is that such a process cannot be stopped without turning the whole vessel on its side, otherwise the steel would run back through the tuyeres at the bottom. It has always been attractive to steelmakers to have a process that can be carried out in a form of ladle, so that it can be stopped at will, samples can be taken, and the necessary additions can be made. The Austrians have achieved this for mild steel by blowing a jet of oxygen down on to the surface of the metal contained in a pear-shaped vessel not unlike a Bessemer converter, but without, of course, the bottom air tuyeres. The impact of the jets sets up a vigorous chemical reaction and provides all the stirring that is necessary. In general, the chemistry of this process is very similar to that of the Thomas process, but with one surprising difference. As I said earlier, in the Thomas process the phosphorus is oxidized into the slag after the carbon is mostly gone. In this top-blowing process, however, the phosphorus comes out together with the carbon or indeed sometimes ahead of it. This has some metallurgical advantages and an interesting chemical explanation.

In top blowing, the ferric oxide formed by the action of the oxygen on the metal no longer has to survive an attack by silicon and carbon but immediately reacts with the lime present on the surface to form a reactive liquid. The slag has an oxygen potential much higher than that of the metal and therefore a reaction takes place between the two. As before, silicon is the first to be oxidized, but the oxidation of carbon is severely handicapped for a number of reasons. First of all the solubility of carbon in slag is effectively zero and the solubility of oxygen in the metal is low, so that carbon–oxygen atom collisions in either phase are infrequent. More important, however, is the fact that the product of combustion, carbon monoxide, has a very low solubility in both phases and effectively exists only as a gas. Because of the surface tension forces it is difficult for bubbles of gas to form in the metal phase or at the slag/metal interface, and because of the low solubility of carbon monoxide, very high supersaturations are necessary before nucleation of bubbles can occur. We have here in top blowing a case of a reaction being slowed down because of the difficulty the products have in getting away. Steelmakers will recognize that similar conditions apply in the open-hearth furnace where iron oxide is added to the slag, but these are not so pronounced as in top blowing.

In contrast with carbon, phosphorus has an easy road in reacting with slag. Practically every atom of phosphorus in the metal which arrives at the slag interface is drawn over into the latter phase by the affinity forces. To achieve its oxidation it needs to give up electrons to the slag, and because of the high concentration of ferric iron, which can take up electrons to form ferrous iron, this is very easy.

We have seen earlier that Thomas by introducing lime made it possible to change the order of oxidation of elements and remove phosphorus before burning the iron. Now with top blowing one can make a second change of order and remove phosphorus before or in parallel with carbon. In comparison with bottom blowing the effect is very large at carbon contents above 0·1%. At 1% carbon the phosphorus partition ratios in top blowing are one thousand times greater than in bottom blowing.

These chemical developments might be restated in a rather oversimplified form. Bessemer failed to remove phosphorus because he provided no place for it to go, that is, no place where it would be at a lower potential than it was in the iron. Thomas provided such a place in a highly oxidizing and basic slag, but he could only achieve the oxidizing conditions when the carbon was removed so that the oxygen could get through the metal to the slag. The Austrians have removed this last restriction by getting the oxygen into place more directly.

Although this process is so far limited to low-phosphorus irons (below 0·2%), where the slag volume is not too great for the oxygen jet to penetrate, it has a number of *potential* advantages in addition to those given above. Carbon steels can be made directly from medium-phosphorus iron without blowing the iron down to very low carbon levels and recarburizing. Because phosphorus can be removed at lower temperatures where higher partition ratios obtain, the losses of iron to the slag need not be so high.

On its present basis, top blowing is making considerable progress in North America as well as in Europe, and some new developments to deal with the higher-phosphorus irons in Great Britain are to be expected. These might well take the form of intermediate processes.

It is of interest to note that these processes of using steam and of top blowing were partly anticipated in Bessemer's patents nearly a hundred years ago.

It would be fitting to conclude this address with a view of the future of pneumatic processes. We have seen that Bessemer's converter is expanding its field through tonnage oxygen and that a new top-blowing process is growing up alongside it. But steelmaking will still depend on the intermediate production of the carbon alloy, pig iron, a product which is not only off the direct route from ore to steel but is also costly to make because of the special requirements of blast-furnaces.

It has been a desire of steelmakers for many generations to develop a direct steelmaking process, that is, one which converts the ore to a low-carbon steel directly. A similar process, the sponge-iron process, has successfully operated in Sweden for some years. This uses carbon monoxide gas to reduce ore at temperatures below 1000° C, where both the ore and the iron product are solid. More recently the Americans have developed the "H-iron process"[4] in which high-pressure hydrogen, produced by modern cheap methods from oil or hydrocarbon gas, is used to reduce powdered ore in a fluidized bed at temperatures near 500° C. These processes cannot make steel because the impurities in the ore cannot be separated. They are important, however, because of their ability to produce for steel furnaces a good feed material if one starts with a high-grade ore.

We have seen that the speed of Bessemer's process came about through the dispersion of air-bubbles in a liquid metal. Similar speed potentialities would exist if we reversed this system and dispersed small droplets of liquid ore in a high-temperature gas. Furthermore, if this gas could be maintained at a low oxygen potential, the ore droplets would be reduced to droplets of liquid metal plus slag. If the oxygen potential is controlled at the correct low value and lime is introduced for the slag, neither silicon, carbon, nor phosphorus need come into the metal and thus the droplets would be a form of steel rather than pig iron. Finally it would be necessary to precipitate the droplets out of the gas and allow the metal to separate from the slag by gravity and surface tension.

Laboratory experiments and technical developments in allied fields indicate that all the above are possible. Accordingly, the British Iron and Steel Research Association is actively engaged in developing such a process under the name 'Cyclosteel.' This is still in its very early stages and nothing like as advanced as Bessemer's process was one hundred years ago. Furthermore, I suspect that even with all the modern techniques and resources at our disposal, it is going to take rather longer than it took Bessemer to get through the practical problems. It has, however,

got away to a promising start and, in the preparatory stages, we have already made small quantities of very crude steel.

The process is best suited for an ore which is already in a finely divided state. Many sources already exist, particularly as products of ore-beneficiating processes. The ore is to be preheated, probably in a fluidized bed to a temperature just below where it becomes sticky, and then injected into the very hot reducing gas. The latter is to be produced by a fuel such as pulverized coal or atomized fuel oil with only sufficient air and oxygen partly to burn it. It is almost certainly necessary to use oxygen to maintain the necessary high temperature and low oxygen potential at one and the same time. From preliminary trials we know that the two reactions, ore plus carbon monoxide going to iron plus slag and carbon dioxide, and coal plus oxygen and carbon dioxide going to carbon monoxide, are fast with finely divided particles and only a short time in the reaction zone seems to be necessary.

The separation of the gas from the precipitated products will take place by gravity and cyclonic centrifugal action, and a settling chamber finally separates the iron from the slag.

It is seen that the Cyclosteel process is an 'inversion' of Bessemer's process in both a physical and a chemical sense. In the latter, fine bubbles of an oxidizing gas are dispersed in an over-reduced liquid metal, while in the former fine droplets of liquid ore or oxidized metal are dispersed in a reducing gas.

The Cyclosteel process is in its very early stages and is only referred to here because of the way it fits into the evolution which began with Bessemer. Formidable technical obstacles stand in the way and will have to be surmounted. On the other hand, a method of making steel from powdered ore and coal is extremely attractive, especially as it avoids the sinter plant and the coke ovens and widens the range of fuels that could be used. It is unlikely to replace the blast-furnace, at least for many years, but if logic can be converted into practice it will take a place among pneumatic steelmaking processes.

Bibliography

1. J. MITCHELL: *J. Iron Steel Inst.*, 1956, vol. 183, June, pp. 179–188.
   H. D. BESSEMER: *Ibid.*, pp. 188–189.
   G. DELBART: *Ibid.*, pp. 190–195.
   A. E. CHATTIN: *Ibid.*, pp. 196–197.
   F. B. CAWLEY and D. R. WATTLEWORTH: *Ibid.*, pp. 198–207.
2. A. B. WILDER: *J. Met.*, 1956, vol. 8, June, pp. 742–753.
   P. COHEUR and H. KOSMIDER: *Ibid.*, pp. 754–759.
3. D. J. O. BRANDT: *Iron Coal Trades Rev.*, 1956, vol. 171, 4th May, pp. 547–554, 558.
4. P. M. UNTERWEISER: *Iron Age*, 1956, vol. 178, 12th July, pp. 71–74.

BESSEMER CENTENARY EXHIBITION 1956

In connection with the celebration of the centenary of Sir Henry Bessemer's discovery of the pneumatic steelmaking process, a small exhibition of portraits, photographs, letters, and other relics was held at the Offices of the Institute, 4 Grosvenor Gardens, S.W.1, from 15th to 18th May, 1956. The following is a catalogue of the exhibits on display at that time: except where otherwise stated, the exhibits were made available by courtesy of the executors of the late Mr. Henry W. Bessemer.

Items marked * were left to Mr. H. Douglas Bessemer and Miss R. E. M. Bessemer by their father, the late Mr. Henry W. Bessemer, with remainder to the Institute. They have been deposited with the Institute on loan by Mr. and Miss Bessemer. Items marked † have been presented to the Institute by Mr. and Miss Bessemer.

Grateful acknowledgment of these presentations and loans has already been made.

PORTRAITS OF BESSEMER AND HIS FAMILY

Portrait in oils of Sir Henry Bessemer, by Rudolf Lehmann (*The Iron and Steel Institute*).

Portrait in oils of Sir Henry Bessemer (artist unknown) —*see* plate facing p. 120

†Mezzotint portrait of Lady Bessemer.

Bust of Sir Henry Bessemer (*Royal School of Mines*).

Engraving of Sir Henry Bessemer (*presented to Mr. K. Headlam-Morley by the late Mr. Henry W. Bessemer*).

Two portraits† and one daguerreotype* of Bessemer as a young man.

"Four Generations"—Sir Henry Bessemer, with his eldest son, eldest grandson, and eldest great-grandson, with a note in Sir Henry's own handwriting (*The Iron and Steel Institute: presented by Sir Henry Bessemer in* 1896).

†Photograph of Sir Henry Bessemer in later years.

†Photograph of Lady Bessemer in later years.

†Cartoon of Bessemer by "Spy."
"Oxo" advertisement, showing head of Bessemer and view of converter (*Mr. F. H. Bessemer Clark*).
Miniatures of Bessemer's father and mother:
One pair, coloured, in two-sided locket (*Miss Bessemer Semon*).
One of each, uncoloured, in small heart-shaped frames.

MEDALS AND HONOURS

*Gold Casket and Freedom of the City of London (1880).
*1851 Exhibition, London: Bronze Medal.
London Exhibition, 1862: Bronze Medal (*Miss Bessemer Semon*).
†Letter from the President of the Royal Board of Trade and Commerce announcing the award to Bessemer by H.M. the King of Württemburg of the Great Gold Medal for the Arts and Sciences in 1863.
*"Comthur" Cross of the Order of Franz Joseph, Austria, 1867.
†Letter from the Chancellor of the Order of Franz Joseph about the award of the "Comthur" Cross of this Order to Bessemer in 1867.
International Exhibition, Paris, 1867: Napoleon Gold Medal (*Science Museum: Gift of Mr. W. Bessemer Wright*, 1938).
Society of Arts, Manufactures and Commerce: Albert Gold Medal, 1872 (*Science Museum: Gift of Mr. W. Bessemer Wright*, 1938).
†Letter from the Society of Arts, Manufactures and Commerce about the award of the Albert Gold Medal for 1872.
London International Exhibition, 1873: Gold Medal (*Miss Bessemer Semon*).
†Letter from (Sir) William Siemens about the election of Bessemer and himself to Honorary Membership of the Königliche Gewerbe Akademie, Berlin, in 1877.
*Carved wooden presentation case containing a bronze plaque and certificate of Honorary Membership of the Verein zur Beförderung des Gewerbfleisses in Preussen, 1877.
†Letter from the above Verein about the despatch of the certificate, including new statutes of the Verein and "Jubel-Feir" publication.
*Howard Quinquennial Prize bowl (now the Howard Gold Medal) of the Institution of Civil Engineers, 1877.
*Society of Arts, Manufactures and Commerce: Albert Gold Medal, 1885.
†Grant of Armorial Bearings to Sir Henry Bessemer, 1880, and letter from College of Arms (Garter).
Certificates of Honorary Membership of:
†The Worshipful Company of Turners of London
†The Worshipful Company of Armourers and Braziers of London
†Niederösterreichischer Gewerb-Verein, Vienna
†The Institution of Civil Engineers, London
†The Society of Engineers, London.
The Bessemer Gold Medal: founded in 1874 (*The Iron and Steel Institute*).
†Certificate of Award of the Bessemer Gold Medal to Edward Windsor Richards in 1884, and signed by Bessemer himself. It was at Bolckow, Vaughan and Co.'s works, of which Richards was manager, that successful dephosphorization was first carried out on a commercial scale.
Bronze Bessemer Medal: Royal School of Mines, London (*Royal School of Mines*).
Letter from Bessemer to the Royal School of Mines offering dies for the Bessemer Medal (*Royal School of Mines*).

PHOTOGRAPHS OF BESSEMER'S BIRTHPLACE AND HOME

†The house at Charlton near Hitchin, the birthplace of Bessemer (three views). Also the nearby mill.

†Bessemer Grange, Denmark Hill: Front view.
†Bessemer Grange, Denmark Hill: The Grotto.
†Bessemer Grange, Denmark Hill: The Observatory.
†Bessemer Grange, Denmark Hill: The Conservatory.
†The telescope erected at Bessemer Grange, Denmark Hill.
†Bessemer's telescope: part of mechanism.
†Bessemer's telescope: interior view.
†The interior of Bessemer's sun furnace.
†The exterior of Bessemer's sun furnace.
A clock, which originally stood in the hall of Bessemer's home at Denmark Hill, and is now in the hall of the Offices of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1 (*The Iron and Steel Institute: presented by the late Mr. Henry W. Bessemer in* 1935).

BESSEMER THE INVENTOR

The Pneumatic Steelmaking Process

Photocopy of *The Times*, dated 14th August, 1856, giving the text in full of Bessemer's lecture "On the Manufacture of Malleable Iron and Steel," read before the British Association for the Advancement of Science at Cheltenham on Monday, 11th August, 1856 (*The Iron and Steel Institute*).
†Reprint of paper by Bessemer "On the Manufacture of Malleable Iron and Steel," read before the Institution of Civil Engineers in May, 1859.
†Reprint of paper by Bessemer "On the Manufacture of Continuous Sheets of Malleable Iron and Steel Direct from Fluid Metal," read before The Iron and Steel Institute in 1891.
W. D. Allen's account of early difficulties in the development of the Bessemer process, given when receiving the Bessemer Gold Medal of The Iron and Steel Institute in 1890 (*J. Iron Steel Inst.*, 1890, No. II, pp. 15–16).
Two *Journals* of The Iron and Steel Institute containing papers by Bessemer.
†Photograph of an early Bessemer plant (possibly at Sheffield).
†Photograph of one of three original Bessemer pits at Ebbw Vale works in 1906, when being dismantled for the erection of a new Bessemer plant.
Photograph of the Ebbw Vale Bessemer Plant before demolition (*The Iron and Steel Institute: presented by the late Mr. Guy Barrett*).
Copy of a water colour painted in 1858 by Carl Cantzler showing the first Swedish Bessemer plant at Edske (*presented by Mr. Fredrik Göransson, Chairman of Sandvikens Jernverks A.B.*).
Copies of two documents and one sheet of photographs in the archives of Sandvikens Jernverks A.B. concerning Bessemer's patent rights in Sweden, 1857 (*presented by Mr. Fredrik Göransson, Chairman of Sandvikens Jernverks A.B.*).
Half-sectional model of Bessemer converter (*Science Museum*).
Diagram of Bessemer process (*Science Museum*).
Showcase of Bessemer steel specimens (*The Iron and Steel Institute: presented by Sir Henry Bessemer*).
Cylindrical vessel made from a very early cast of Bessemer steel (*Mrs. Howard Bessemer*).
Vase made from a very early cast of Bessemer steel (*Mrs. Howard Bessemer*).

Small model anvil made from the first Bessemer ingot produced at Ebbw Vale, about 1863–4 (*The Iron and Steel Institute: presented by the late Mr. Guy Barrett*).

†Article and illustration from *The Illustrated London News*, September, 1856.

Other Inventions

†Photograph of rifled projectile designed by Bessemer. Artillery experts of the time were doubtful whether existing ordnance could fire such projectiles without bursting. Bessemer's subsequent search for improved materials eventually led him to the development of the converter process of steelmaking.

*Two bronze plaques cast by Bessemer.

†" Napoleon and Josephine "; photograph of a medallion cast by Bessemer.

†Four copper electrotype impressions from the dies of the Napoleon Medals on which Bessemer carried out his first experiments on the electrodeposition of copper. This work antedated that of Jacobi in St. Petersburg by about six years.

†Instrument for controlling the firing of naval guns.

†Reprint of paper " On the Accurate Firing of Naval Ordnance by means of the Vessel's Motion ": read at the Royal Naval College, Greenwich, 1873.

†An impression (water-colour) of the saloon of the *S.S.* " *Bessemer* " intended to reduce the sufferings of bad sailors on the Channel crossing.

A decorative wooden panel from the saloon of the *S.S.* " *Bessemer* " (*The Iron and Steel Institute: presented by Mr. W. A. Woodward in* 1950).

†Photograph of the saloon of the *S.S.* " *Bessemer*."

†Photograph of the *S.S.* " *Bessemer* " in dry-dock.

Seven atlases of drawings illustrating Bessemer's patents (*The Iron and Steel Institute: presented by the late Mr. Henry W. Bessemer in* 1951).

Bessemer's " Autobiography," published posthumously in 1905 (*The Iron and Steel Institute*).

Subsequent to the Exhibition Mr. H. Douglas Bessemer and Miss R. E. M. Bessemer also presented a volume " In Memoriam—Sir Henry Bessemer," being a collection of all the obituary notices which appeared in the press of the world on Sir Henry Bessemer's death.

OTHER ARTICLES NOT DISPLAYED IN THE EXHIBITION

†Azimuth dial.

†Balance and weights.

†Small electrical machine.

Silvered replicas of the obverse and reverse of the Royal School of Mines Bessemer Bronze Medal.

Bronze replica of the Bessemer Gold Medal, 1873 (*Miss Bessemer Semon*).

*Another bronze replica of the Bessemer Gold Medal.

*Replica on wax of the Bessemer Medal (obverse).

†Photographic negative of two portraits of Bessemer.

†Cutting from *The Times* of 12th February, 1956, showing the portrait by Lehmann, Consett Works, annotated by the late Mr. Henry W. Bessemer.

†Two photographs of Bessemer in later years; *see also* " Portraits," p. 118.

†Two further photographs of the four generations (in different poses); *see also* " Portraits," p. 118.

†Photograph of Joseph Whitworth, with Fairbairn, Napier, and Penn, Manchester.

†Photograph of British Association meeting, Southampton, 1882.

†A further photograph of Bessemer's telescope; *see also* " Photographs," p. 119.

†A further photograph of Bessemer's sun furnace; *see also* " Photographs," p. 119.

†Another photograph of Bessemer Grange, Denmark Hill; *see also* " Photographs," p. 119.

†Leaflet of press notices on the " Autobiography."

†One further photograph of Lady Bessemer in later years; *see also* " Portraits," p. 118.

†Photograph of Grand Prix Medal, Paris Exhibition, 1867.

†Photograph of plaque of head of Minerva.

†Photograph of two plaques of classical scenes.

†Photograph of a drawing for a proposed glassworks.

†Institution of Civil Engineers, certificates of associateship and of membership; *see also* " Medals and Honours," p. 119.

IRON AND STEEL GALLERY AT THE SCIENCE MUSEUM

In co-operation with the Science Museum, South Kensington, the British Iron and Steel Federation is composing a new ferrous metallurgical display in the Museum to commemorate Sir Henry Bessemer, F.R.S. A sum of £50,000 has been allocated for this purpose. The following is a short survey of the proposed display, which will be completed within three years.

INTRODUCTION

THIS permanent exhibition is to give a three-dimensional picture of the development of the industry all over the world, from its primitive origins up to the present day, with special emphasis on the very considerable British contribution.

It is not an easy task to tell this story in the available space, which is limited to 3500 ft². Obviously the content will have to be condensed to the most salient facts. Complicated chemical reactions, works' practices, and specialized machinery and methods will, in many cases, only be indicated.

Treatment

Use will be made of exhibits in three dimensions to illustrate the story. As much original equipment as possible and many samples and models will be included in the display. Movement will be incorporated where practicable.

Flat material will be restricted to those items where three-dimensional treatment proves to be impossible. This applies mainly to the numerous flow charts, which will, however, nearly all be animated by light flow.

The dramatic glow of molten metal and the sparks so characteristic of steelmaking will be shown by colour transparency. Where very great depths are involved, stereoscopic transparencies will be chosen as the presentation medium.

Summary

It is not intended—nor indeed is it possible—to give a complete picture of the industry, but this display will endeavour to give a representative outline in such a way as to stimulate and hold the interest both of the student and of the casual visitor from beginning to end.

CONTENT OF EXHIBITION

Area A: *HISTORY OF IRONMAKING*

A–1 to A–7*a*	History of wrought-iron making (direct from ore)
A–8 to A–13*a*	History of pig-iron making
A–14 to A–21	History of wrought-iron making from pig iron

Area B: *HISTORY OF STEELMAKING*

B–1 to B–4*b*	Pre-Bessemer steels
B–5 to B–9	Bessemer's invention

Area C: *MODERN IRONMAKING*

C–1 to C–10	The blast-furnace
C–11 to C–19	Raw products for ironmaking

Area D: *MODERN STEELMAKING*

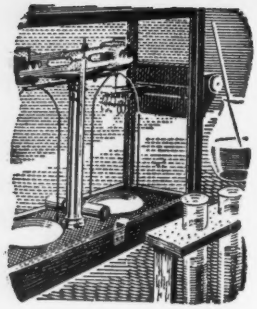
D–1 to D–10	The four principal steelmaking processes
D–11 to D–20	Grades of steel

Area E: *SHAPING OF STEEL*

E–1 to E–3	Steel casting
E–4 to E–9	Steel ingots
E–10 to E–15	Forging
E–16	Continuous casting
E–17 to E–22	Rolling
E–23	Wire drawing
E–24 to E–27	Tube making

Area F: *THE STEEL AGE*

F–1	Integrated steelworks
F–2 to F–4	The importance of iron and steel
F–5 to F–9	Steel metallurgy
F–10	Why is steel strong ?
F–11	Testing of steel
F–12 to F–14	Steel research



PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research

Study of 7% and 8% Chromium Creep-resisting Steels

FOR USE IN STEAM POWER PLANT

By M. G. Gemmill, H. Hughes, J. D. Murray, F. B. Pickering, and K. W. Andrews

SYNOPSIS

The study of 7% and 8% chromium creep-resisting steels to bridge the gap at present existing between available low-alloy and austenitic materials used in steam power plant was the objective leading to the research work reported in this paper. This is divided into three parts. The first is concerned with the preliminary development work on various 7% Cr base steels of duplex constitution. The second details the results of a systematic study of the metallurgical characteristics of various 8% Cr, 3% Mo steels, ferritic at all temperatures. In the third part the properties of an 8% Cr–Mo–Ti steel selected from the foregoing systematic study are outlined in relation to those of 2¼% Cr–Mo ferritic, and 18/12/1 austenitic creep-resisting steels. 1163

THE CONTINUING EXPANSION of power plant in Britain since 1945 has meant not only more power stations, but also power stations of higher thermal efficiency, exemplified by a turbine stop-valve pressure of 2350 lb/in² and a steam temperature of 566° C (1050° F) in a modern unit having a thermal efficiency of 42·9%.[1] These more severe operating conditions require metals to function at temperatures up to 621° C (1150° F) in the hottest section of the superheater of such a unit.

As long as the maximum metal temperature of boiler plant remained below 566° C, it was possible to meet the service demands by the use of low-alloy ferritic creep-resisting steels. Above 566° C, or at the most 593° C (1100° F), these materials possess neither adequate creep strength nor scaling resistance, and it has become necessary to turn to austenitic steel to meet these requirements.

The use of an austenitic steel brings with it the problem of joining it to a ferritic steel of lower thermal-expansion in some part of the steam plant, and it would be desirable on these grounds, and on the equally pertinent one of first cost, to extend the use of creep-resistant ferritic material to metal temperatures of 621° C.

It has been determined that to produce scaling resistance at 621° C equivalent to that of a 1% Cr–Mo steel at 566° C, between 7% and 8% chromium must be present; this fact imposes a serious limitation in attaining the other objective of creep resistance, because steels containing only 7–8% Cr and no other alloying elements are inherently weak at elevated temperatures. This paper outlines an approach which has been made to overcome the difficulties which arise in coping with the ever-increasing demands of industry in this field of metal usage.

The paper is divided into three parts, the first of which deals briefly with the preliminary development work on intermediate chromium steels. The second and third parts present respectively the structural aspects and the properties of a series of fully ferritic experimental steels, together with those of one steel of a composition formulated from the experimental work.

Part I—PRELIMINARY DEVELOPMENT WORK

For reasons already stated, 7% chromium was taken as the base composition and the effects of molybdenum and aluminium were investigated on the low-deformation creep behaviour (3 tons/in² at 620° C), using steels of two carbon levels (0·04–0·06% and 0·11–0·13%). It was shown that:

(i) In the absence of aluminium, there was a marked increase in creep strength when the molybdenum content was increased up to 3%.
(ii) The effect of increasing the aluminium content up to 0·74% in steels containing 3% molybdenum

Manuscript received 19th May, 1955.
Mr. Gemmill, formerly with the United Steel Companies Ltd., is now with the Central Electricity Authority; the other authors are with the Research and Development Department of the United Steel Companies Ltd.

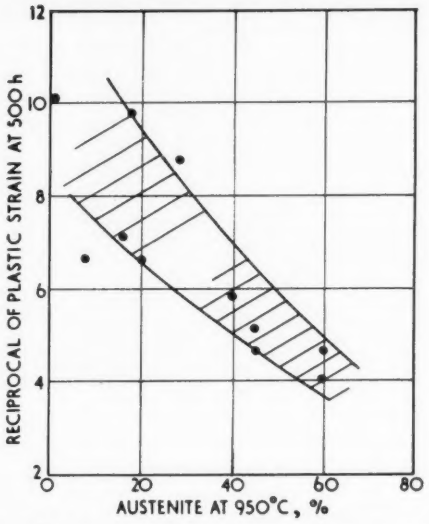


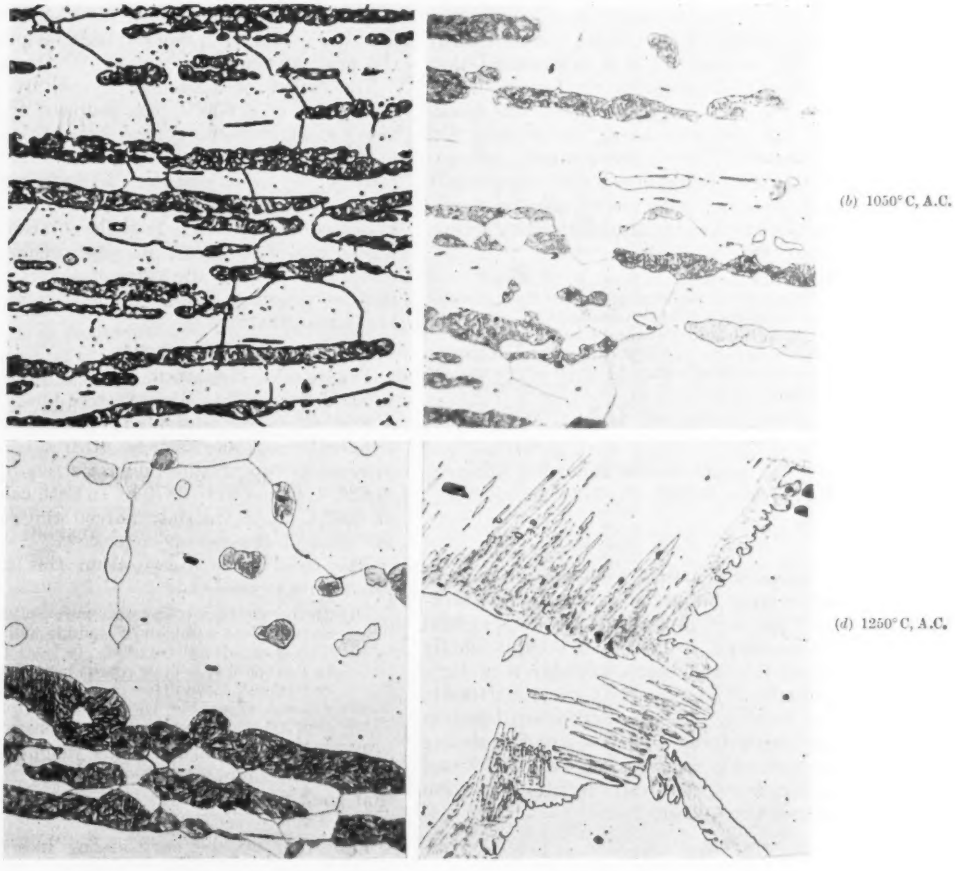
Fig. 1—Effect of constitution on the creep strength of 7% Cr base steels

indicated that optimum creep strength could be obtained with an aluminium content of 0·5%.

(iii) With base composition 7% Cr, 3% Mo, 0·5% Al, the effect of increasing the carbon content from 0·04% to 0·11–0·13% was to cause a marked decrease in creep resistance.

The constitution of the steels at 950° and 1050° C was determined microscopically. Most of the steels were in the two-phase region ($\alpha + \gamma$) at both solution treatment temperatures. The effect of both molybdenum and aluminium was to increase the amount of ferrite relative to austenite at the solution temperatures. Aluminium was the more potent in this respect at the lower carbon levels, but of a similar order to molybdenum at the higher carbon levels. The main structural differences due to the carbon content was the amount of carbide out of solution at 950° C; the lower-C steels showed little undissolved carbide, whilst the higher-C steels contained considerable amounts.

A marked correlation was obtained between the creep strength and the constitution of these steels: the greater the amount of ferrite in the structure the higher the creep resistance (Fig. 1). A more detailed study of this feature revealed that it was the quasi-viscous or secondary creep component of the deforma-

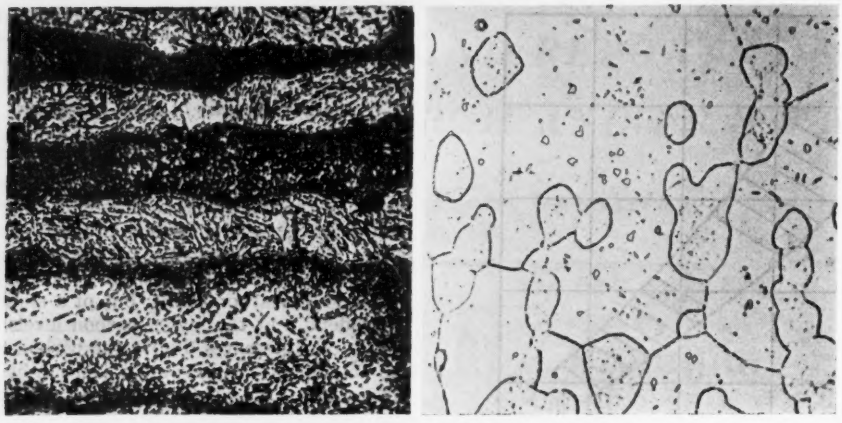


(*a*) 950° C, A.C. (*b*) 1050° C, A.C.

(*c*) 1150° C, A.C. (*d*) 1250° C, A.C.

Note: Villela's reagent (HCl–picral) used as etchant for all specimens

Fig. 2—Microstructures of 7% Cr, 3% Mo, ½% Al, steel × 250



(*a*) 1050° C, A.C., 30 h, 650° C × 750 (*b*) 1050° C, A.C., 10 h, 750° C × 750

Fig. 3—7% Cr, 3% Mo, ¼% Al, steel; effect of tempering on the microstructure

tion which was reduced, and only when some carbide was out of solution was the transient component affected, carbide out of solution being beneficial. A possible explanation for the strengthening due to increased amounts of ferrite might be found in the fact that carbide precipitation during testing mainly took place in the ferrite and if it is assumed that precipitation of carbide reduces the quasi-viscous flow, then the less austenite, the lower the quasi-viscous creep. On the other hand, the transformed austenite consists of very fine-grained acicular products, and as quasi-viscous flow is said to be mainly grain-boundary flow, the effect may also be partly a result of the fine grain of the transformed austenite. It thus appeared that:

(i) A steel of composition 7% Cr, 3% Mo, ¼% Al revealed promising high-temperature strength and therefore merited further examination
(ii) Further work should be aimed to examine fully ferritic materials in which a carbide precipitation would occur during creep testing or service at temperature.

The Metallurgy of a 7% Cr, 3% Mo, ¼% Al, Steel

On the basis of the foregoing work a cast of steel (No. A.13176) was made to the following analysis: 0·06% C, 0·46% Mn, 0·39% Si, 7·20% Cr, 3·40% Mo, 0·52% Al.

Constitution

The constitution of the steel was determined over the temperature range 950–1250° C, the results showing that whilst the steel lay within the $(\alpha + \gamma)$ field over most of this range, at 1250° C it became wholly ferritic. Typical microstructures are shown in Figs. 2*a–d*. The austenite at temperature formed martensite on subsequent cooling. The feathery constituent in Fig. 2*d* is martensite formed from acicular austenite which precipitated as a semi-Widmannstätten structure on cooling from the fully ferritic condition (1250° C) through the γ loop.

The Effect of Tempering

Tempering treatments at 650° and 750° C revealed that the mode of precipitation of carbide was entirely different at these two temperatures. At 650° C, a dense precipitate of M_6C type of carbide formed preferentially around the prior austenite areas, the dispersion being very fine and dense (Fig. 3*a*). On the other hand, tempering at 750° C resulted in a very coarse precipitation of the same carbide in the ferrite (Fig. 3*b*), with no localized precipitation around the prior austenite.

The degree of hardening caused by the localized precipitation at 650° C was followed by micro-hardness determinations, typical behaviour being shown in Fig. 4. It will be noted that the steel hardens more fully in the locality of the austenite/ferrite interface.

X-ray analyses of electrolytically extracted residues indicated that the carbide at the solution temperature was of the $M_{23}C_6$ type, but that precipitated at 650° and 750° C was of the type M_6C. It also appeared that reversion of $M_{23}C_6$ to M_6C took place at the lower temperatures.

High-temperature Properties

The effects of solution temperatures of 950° and 1050° C, followed by the effect of tempering for 30 h at 650° C, were investigated. Increasing the solution temperature from 950° to 1050° C resulted in an increase in rupture life under a stress of 7·0 tons/in² at 625° C from 640 to 3870 h. In both cases, tempering at 650° C approximately halved the rupture life of the solution-treated specimens.

The conclusions drawn from this rather limited investigation were that:

(i) Better rupture properties were obtained by having as complete solution of carbide as possible
(ii) The sluggish nature of the $(\gamma \rightarrow \alpha)$ transformation in a steel of this type might lead to practical heat-treatment difficulties
(iii) It was desirable to cause precipitation during service (or testing), rather than prior to it.

This latter conclusion lends weight to the results obtained on the initial series of steels, which indicated that such behaviour was desirable in a fully ferritic steel.

Following up the very strong indications that a precipitation hardening fully ferritic steel was desirable, it was clear that a more potent ferrite-forming element would have to be introduced, since

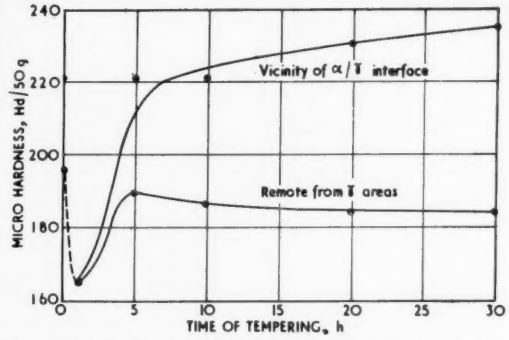


Fig. 4—7% Cr, 3% Mo, ½% Al, steel; localized precipitation hardening characteristics. Hardness of ferrite

optimum creep resistance had been obtained with 0·5% aluminium and it was not deemed economical to increase the molybdenum content. Titanium was selected because of its powerful ferrite-forming tendency, the aluminium now being thought unnecessary. At the same time it was decided to determine whether any benefit could be obtained by increasing the chromium content, and if so whether any reduction in the molybdenum content could then be tolerated.

A series of steels was made with these objectives in view, and tested under rupture conditions (11·0 tons/in² at 625° C). The results shown in Fig. 5 clearly indicate that no benefits were to be gained by modifications to either the chromium or molybdenum contents. It was decided, therefore, to base the composition of the steel upon 8% Cr and 3% Mo, with sufficient titanium to make the steel fully ferritic, and to investigate such a type of steel in detail.

Part II—STRUCTURAL AND THEORETICAL ASPECTS

The structural studies which are to be described in this section were carried out upon a further series of 39 experimental steels detailed in Table I, with the object of examining their constitution in relation to their high temperature properties. The more technical and practical features of one selected composition are considered in the third part of the paper.

EXPERIMENTAL PROCEDURE

The preliminary investigation already discussed in Part I led to the choice of a 7%–8% Cr, 3% Mo base

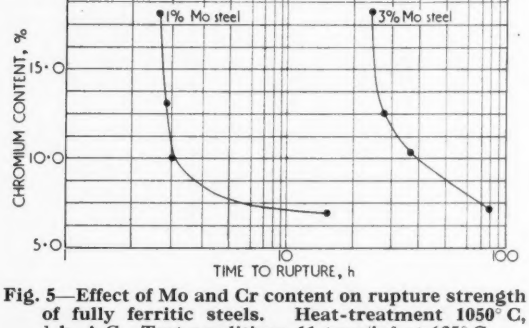


Fig. 5—Effect of Mo and Cr content on rupture strength of fully ferritic steels. Heat-treatment 1050° C, ½ h, A.C. Test conditions 11 tons/in² at 625° C

Table I

CHEMICAL ANALYSES (EXPERIMENTAL STEELS)*

Steel No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Analysis, %	C	0·06	0·04	0·10	0·06	0·10	0·06	0·08	0·04	0·07	0·05	0·07	0·14	0·14	0·19	0·24	0·07	0·07	0·06	0·06	0·06	0·05	0·05	0·06	0·06	0·06	0·06	0·06	0·08	0·05	0·05	0·06	0·07	0·06	0·05	0·05	0·06	0·06	0·06	0·06
	Mn	0·55	0·50	0·54	0·53	0·57	0·55	0·53	0·60	0·51	0·56	0·50	0·62	0·62	0·60	0·53	0·47	0·44	0·43	0·60	0·54	0·58	0·47	0·42	0·48	0·53	0·32	0·50	0·48	0·57	0·49	0·45	0·54	0·55	0·45	0·53	0·56	0·54	0·59	0·52
	Si	0·67	0·63	0·63	0·61	0·60	0·68	0·67	0·56	0·69	0·75	0·82	0·80	0·67	0·65	0·64	0·36	0·48	0·54	0·71	0·67	0·68	0·30	0·28	0·32	0·44	0·30	0·34	0·57	0·50	0·37	0·31	0·52	0·46	0·45	0·49	0·51	0·63	0·74	0·87
	Cr	8·06	7·73	8·04	8·12	8·17	7·92	8·05	7·60	7·91	8·16	8·15	7·84	7·48	7·52	7·46	9·92	12·06	14·28	7·95	7·91	7·80	8·05	7·77	7·91	8·06	8·08	8·15	7·95	8·21	8·21	8·08	11·54	8·24	8·19	8·13	8·11	7·89	7·65	7·96
	Mo	3·20	3·22	3·26	3·24	3·18	3·20	3·12	3·10	3·12	3·11	3·12	3·14	3·08	3·13	3·05	3·07	3·11	3·07	1·03	1·02	1·06	4·16	3·12	3·19	3·09	3·15	3·16	3·15	3·11	3·16	3·15	2·95	3·04	2·98	2·05	2·10	1·05	1·03	3·11
	Ti	0·39	0·53	0·77	0·83	0·99	1·15	1·33	1·39	1·95	2·08	3·17	0·71	0·71	0·94	0·98	1·61	1·62	1·70	1·21	2·10	2·88	1·67	0·39	0·44	1·07	1·03	1·04	1·17	1·30	1·50	1·71	0·74	1·46	1·83	1·42	1·55	1·29	2·49	1·52
	Nb	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1·02	2·00	0·20	0·50	0·93	1·05	1·28	...	...	...	...	...	...	...	0·29	0·30	1·18
	Al	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0·63	1·80	0·73	1·50	...	...	...
	V	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1·05	...	...	...	...	...	...	...	0·12
	W	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0·76	...	...	...	...	...	...	...	...	0·96
Composition variable†		Titanium											Carbon				Chromium			Molybdenum and Titanium				Niobium and Titanium						W and Ti	V and Ti	Cr and Ti	Al and Ti	Al, Mo, and Ti	Nb, Mo, and Ti	Nb, V, W, and Ti

* Relative to 0·04-0·10% C, 8% Cr, 3% Mo, base
† The chemical analysis of two commercial casts is given in Part III of the Paper

Table II

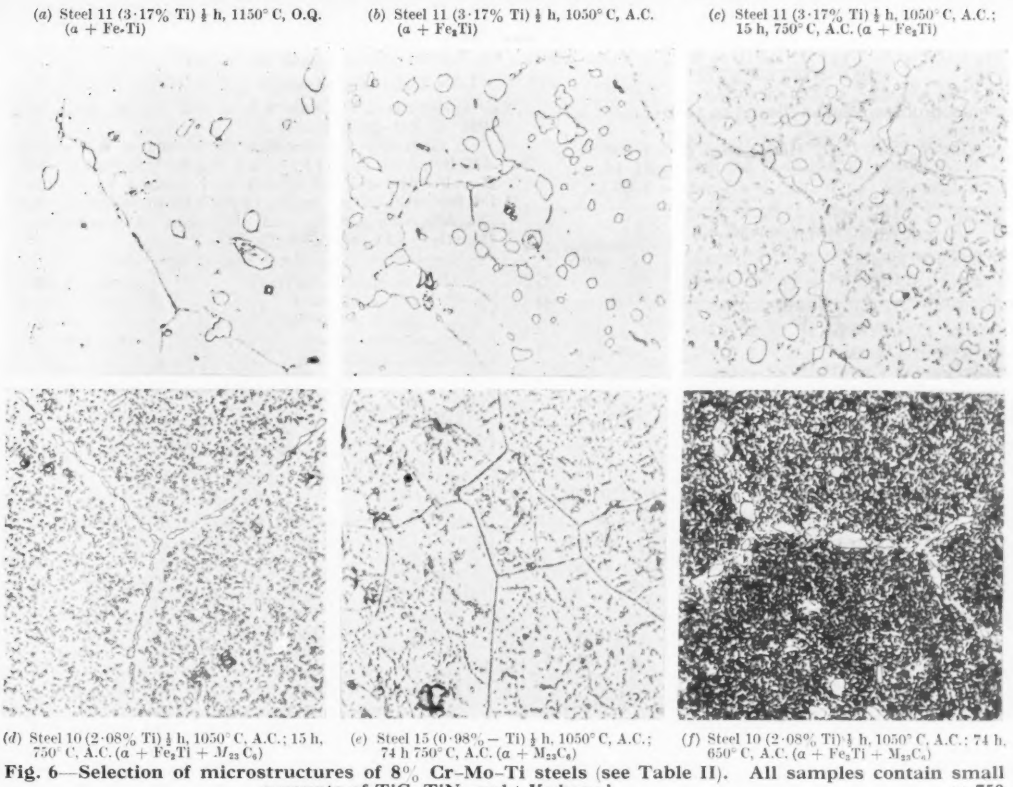
CONSTITUTION OF STEELS—PRECIPITATED PHASES DETERMINED BY MICROSCOPICAL AND X-RAY EXAMINATION

Steel No.	1	2	3	4	5	6	7	9	10	11	12	14	15	16	17	18	19	20	21
1150° C, 20 min, O.Q.	TiC *s*	TiC *s*	TiC *m*	TiC *s*	TiC *l*	TiC* *m*	TiC*	TiC	TiC	TiC* *L*	TiC*	TiC	TiC	...	...	...	...	...	...
1050° C, 30 min, O.Q.	TiC*	...	...	...	TiC*	TiC	TiC*	TiC* *Ls*	TiC* *L*	TiC* *L*	TiC*	TiC*	TiC*	TiC*	TiC*	TiC*	TiC*	TiC*	TiC* *L*
1050° C + 950° C, 1 h	TiC*	TiC	TiC	TiC	TiC	TiC* *Ls*	TiC *Ls*	TiC *Lm*	TiC* *L*	TiC* *Ll*	TiC	TiC	TiC	TiC* *Ls*	TiC* *Ls*	TiC *Lm*	...	...	...
1050° C + 850° C, 5 h	TiC* *Ltr*	TiC* *Ls*	TiC *Ls*	TiC *Lm*	TiC *Ll*	TiC* *Ll*	TiC *Ll*	TiC* *Ll*	TiC* *Ll*	TiC* *Ll*	TiC *Ltr*	TiC *Ltr*	TiC*	TiC *L*	TiC* *L*	TiC *L*	...	...	...
1050° C + 750° C, 14 h	TiC* *Ls*	TiC *L*	TiC *L*	TiC *L* *Ktr*	TiC *L* *Ktr*	TiC* *L* *Ktr*	TiC* *L*	TiC *L* *Ktr*	TiC* *L* *Ktr*	TiC* *L*	TiC* *Ls*	TiC *Ls*	TiC *Ls*	TiC *L*	TiC* *L* *Ktr*	TiC *L*	...	...	...
1050° C + 650° C, 72 h	TiC *K*	TiC *K*	TiC *Kl*	TiC *Kl*	TiC *Kl*	TiC* *Kl*	TiC* *L* *K*	TiC* *L* *Kl*	TiC* *L* *K*	TiC* *L* *K*	TiC* *K*	TiC *K*	TiC* *K*	TiC *K*	TiC *K*	TiC *K*	...	...	...
1050° C 550° C†	...	...	...	...	...	TiC* *K*	TiC *Kl*	TiC *Kl*	...	TiC *L* *K*	TiC *K*	TiC *K*	TiC *K*	...	...	...	...	...	...

Steel No.	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
1050° C, 30 min, O.Q.	TiC*	(Nb,Ti)C* *L'*	NbC* *L'*	(Ti,Nb)C* *L' tr*	(Nb,Ti)C* *L' tr*	(Nb,Ti)C* *L'*	(Ti,Nb)C* *L'*	(Ti,Nb)C* *L'*	(Ti,W)C*	(Ti,V)C* *L tr*	TiC	TiC* *L tr*	TiC* *L tr*	TiC* *L tr*	TiC* *L tr*	(Ti,Nb)C*	(Ti,Nb)C* *L'*	(Ti,Nb,W,V)C* *L' l*
1050° C + 950° C, 1 h	TiC *Lm*	(Nb,Ti)C *L' l*	NbC *L' l*	(Ti,Nb)C *L' s*	(Nb,Ti)C *L' m*	(Nb,Ti)C *L' l*	(Ti,Nb)C *L' m,l*	(Ti,Nb)C *L'*	(Ti,W)C *L' m*	(Ti,V)C *L s*	TiC	TiC *Ls*	TiC *Ll*	TiC* *Ltr*	TiC *L*	...	...	(Ti,Nb,W,V)C* *L' l*
1050° C + 850° C, 5 h	TiC *L*	(Nb,Ti)C *L'*	NbC* *L'*	(Ti,Nb)C* *L'*	(Nb,Ti)C *L'*	(Nb,Ti)C *L'*	(Ti,Nb)C *L'*	(Ti,Nb)C *L'*	(Ti,W)C *L'*	(Ti,V)C *L*	TiC *Ls*	TiC *L*	TiC *L*	TiC *L*	TiC* *L*	...	...	(Ti,Nb,W,V)C *L'*
1050° C + 750° C, 14 h	TiC* *L*	(Nb,Ti)C *L'*	NbC *L'* *Ktr*	(Ti,Nb)C *L'* *Ktr*	(Nb,Ti)C *L'* *Ktr*	(Nb,Ti)C *L'*	(Ti,Nb)C *L'*	(Ti,Nb)C *L'* *Ktr*	(Ti,W)C *L'* *Ktr*	(Ti,V)C *L*	TiC *Lm*	TiC *L* *Ktr*	TiC* *L*	TiC *L*	TiC *L*	...	...	(Ti,Nb,W,V)C* *L'*
1050° C + 650° C, 72 h	TiC *K*	(Nb,Ti)C *L'* *K*	NbC (Ti,Nb)C* *L'* *K*	(Ti,Nb)C* *L'* *K*	(Nb,Ti)C *L' tr* *K*	(Nb,Ti)C *L'* *K*	(Ti,Nb)C *L'* *K*	(Ti,Nb)C* *L'* *K*	(Ti,W)C *K*	(Ti,V)C *L tr* *K*	TiC *K*	TiC *L tr* *K*	TiC *L tr* *K*	TiC *L tr* *K*	TiC* *L tr* *K*	...	...	(Ti,Nb,W,V)C *L'* *K*

Key and Notes:
1. All samples had the *α*-ferrite matrix; TiN and ' *Y* phase ' were generally present as well
2. TiC generally present, but sometimes obscured amounts of other constituents
3. The table gives TiC, NbC, and precipitated phases only
4. Amounts: *tr* = trace for all; *s* = small; *m* = medium; *l* = large

* Signifies both X-ray and microscopical examination; otherwise microscopical only
† 550° C samples were heated for varying times for age-hardening tests
K = Carbide $M_{23}C_6$
L = Fe_2Ti (Laves phase)
L' = Fe_2Ti containing Nb or W



(*a*) Steel 11 (3·17% Ti) ½ h, 1150° C, O.Q. (α + Fe$_2$Ti)

(*b*) Steel 11 (3·17% Ti) ½ h, 1050° C, A.C. (α + Fe$_2$Ti)

(*c*) Steel 11 (3·17% Ti) ½ h, 1050° C, A.C.; 15 h, 750° C, A.C. (α + Fe$_2$Ti)

(*d*) Steel 10 (2·08% Ti) ½ h, 1050° C, A.C.; 15 h, 750° C, A.C. (α + Fe$_2$Ti + $M_{23}C_6$)

(*e*) Steel 15 (0·98% — Ti) ½ h, 1050° C, A.C.; 74 h 750° C, A.C. (α + $M_{23}C_6$)

(*f*) Steel 10 (2·08% Ti) ½ h, 1050° C, A.C.; 74 h, 650° C, A.C. (α + Fe$_2$Ti + $M_{23}C_6$)

Fig. 6—Selection of microstructures of 8% Cr–Mo–Ti steels (see Table II). All samples contain small amounts of TiC, TiN, and '*Y* phase' × 750

composition. From this starting point the preliminary work had indicated the desirability of investigating thoroughly the effect of titanium, and to a more limited degree the effect of certain other elements. The chemical analyses of all the experimental steels covered in the present study are recorded in Table I. These steels are grouped together according to the various elements whose composition was varied in turn. An attempt to assess the effect of additions or substitutions of the other elements indicated accounts for the remaining steels.

The experimental work employed the following methods:

(*a*) Microscopical examination of specimens after solution treatments at 1150° and 1050° C and after reheating treatments subsequent to solution at 1050° C. The reheating temperatures were 550°, 650°, 750°, 850°, and 950° C. It was not considered necessary to carry out detailed examination of all the steels in all these conditions of heat-treatment.

Standard methods of preparation were used except that in the later part of the work diamond-polishing became available, enabling much better retention of the hard particles Etching methods were also standard, Vilella's HCl–picral reagent being found very suitable The very fine degree of dispersion of some of the carbides and compounds formed at low temperatures rendered complete identification by etching impossible and more attention was given to the form and dispersion of the precipitates.

(*b*) Hardness determinations were carried out on all specimens in the conditions of heat-treatment described above, and on certain steels precipitation hardening characteristics were determined at temperatures of 550°, 650°, 750°, 850°, and 950° C

(*c*) The X-ray analysis of the steels involved two complementary techniques:

(i) lattice parameter measurements were made using a back-reflection technique and solid specimens from a suitable selection of the steels were examined by this method in different conditions of heat-treatment;

(ii) the identification by powder photographs of the constituents present in residues separated from selected specimens by electrolytic solution (electrolyte used was a saturated ferric-chloride solution).

RESULTS

The phases present in each steel after the standard conditions of heat-treatment described previously are listed in Table II. X-ray examination was confined to a selection of the steels and the data so obtained are indicated for these cases in the Table. In the other cases the phases were determined by microscopical examination only. A selection of microstructures is illustrated in Fig. 6. The following observations relating to the occurrence of the various constituents will help to clarify subsequent discussion.

Constituents Present

Titanium Carbide (TiC)

This phase is present at all temperatures between 1150° C and 550° C. There was some evidence that amounts at the lower temperatures were in excess of equilibrium requirements and slight re-solution might occur. As previously noted[2, 3] this constituent appears to form a solid solution with TiN, but only to a limited extent. Similarly the TiN phase does not appear to have dissolved much TiC, under the con-

Table III

X-RAY POWDER DIFFRACTION DATA FOR TWO CONSTITUENTS

(*a*) '*Y* Phase'

Analysis unknown but believed to be a second nitride of titanium.

Provisional Unit Cell: Hexagonal $a = 3{\cdot}206$ Å, $c = 11{\cdot}19$ Å, $c/a = 3{\cdot}49$

Intensity*	Interplanar Spacings, Å		Indices *hkil*
	Observed	Calculated	
w	2·788	2·777	$10\bar{1}0$
s	2·230	2·227	$10\bar{1}3$
vvw	1·977	1·971	$10\bar{1}4$
w	1·870	1·871	0006
vvw	1·740	1·743	$10\bar{1}5$
m	1·603	1·603	$11\bar{2}0$
w	1·550	1·548	$10\bar{1}6$
vw	1·385	1·387	$20\bar{2}0$, $10\bar{1}7$
m+	1·303	1·302	$20\bar{2}3$
wm	1·214	1·215	$11\bar{2}6$
w	1·135	1·134	$10\bar{1}9$
vvw†	1·047	1·045	$21\bar{3}1$
wm	1·0096	1·0103	$21\bar{3}3$
vw	0·9547	0·9550	$10\bar{1}11$
vw	0·9493	0·9502	$12\bar{3}5$
w	0·9264	0·9262	$20\bar{2}9$
w+†	0·9249	0·9257	$30\bar{3}0$
vw†	0·9142	0·9133	$30\bar{3}2$

* s = strong, w = weak, m = medium, vw = very weak, etc.
† These lines may be overlapped by lines of another constituent

(*b*) Laves Phase based on Fe_2Ti

Unit Cell: Hexagonal

(1) (*a*) Steel 11 after 5 h at 850° C; (*b*) Steel 24 after 1050° C (oil-quenched)

(2) Chemical analysis of (*a*) indicates a composition AB_2 in which A = Ti about $\frac{1}{2}$ of which is replaced by Mo, B = Fe about $\frac{1}{4}$ of which is replaced by Cr and Si; i.e. formula based on Fe_2Ti with solid solution—approx. $(Ti_{20}Mo_{11})(Fe_{50}Cr_3Si_9)$: cf. formula of VerSnyder and Beattie[6]—$(Ti_{21}Mo_9)(Fe_{50}Cr_5Si_5)$.

Indices *hkil*	(*a*) Near to Fe_2Ti: $a = 4{\cdot}766$ Å, $c = 7{\cdot}759$ Å, $c/a = 1{\cdot}628$			(*b*) $Fe_3(Ti, Nb)$: $a = 4{\cdot}795$ Å, $c = 7{\cdot}816$ Å, $c/a = 1{\cdot}630$		
	I†	Interplanar Spacing, Å		I†	Interplanar Spacing, Å	
		Observed	Calculated		Observed	Calculated
$10\bar{1}2$			(2·8267)	vvw	2·8107	2·8458
$11\bar{2}0$	m	2·3600	2·3828	m	2·3757	2·3973
$10\bar{1}3$	ms	2·1694	2·1915	s	2·1862	2·2068
$20\bar{2}0$	vw	2·0426	2·0635			(2·0761)
$11\bar{2}2$	s	2·0125	2·0303	s	2·0263	2·0435
$20\bar{2}1$	s	1·9770	1·9943	ms	1·9890	2·0065
0004	wm	1·9228	1·9397	w	1·9407	1·9539
$20\bar{2}2$	wm	1·8065	1·8219	vw	1·8124	1·8335
$10\bar{1}4$	wm	1·7443	1·7555	w	1·7530	1·7680
$21\bar{3}1$	vvw	1·5209	1·5293			(1·5387)
$10\bar{1}5$	w	1·4433	1·4524	wm	1·4554	1·4629
$30\bar{3}0$	w	1·3685	1·3757	wm	1·3784	1·3841
$21\bar{3}3$	ms	1·3294	1·3358	ms	1·3396	1·3443
0006 } $30\bar{3}2$	ms	1·2909	1·2931 1·2966	ms	1·2995	1·3026 1·3047
$20\bar{2}5$	ms	1·2356	1·2402	ms	1·2454	1·2491
$30\bar{3}3$ } $21\bar{3}4$	wm	1·2118	1·2145 1·2156	w	1·2207	1·2224 1·2236
$22\bar{4}0$	ms	1·1879	1·1914	ms	1·1956	1·1986
$11\bar{2}6$			(1·1366)	vvw	1·1413	1·1445
$21\bar{3}5$	w	1·0995	1·1000			(1·1074)
$20\bar{2}6$ } $31\bar{4}2$	m	1·0934	1·0958 1·0980	ms	1·1031	1·1033 1·1046
$10\bar{1}7$	vw	1·0688	1·0706	vw	1·0767	1·0783
$31\bar{4}3$	s	1·0449	1·0467	s	1·0517	1·0532
$40\bar{4}0$			(1·0319)	vw	1·0374	1·0381
$40\bar{4}1$	m	1·0217	1·0229	m	1·0276	1·0291
$22\bar{4}4$	m	1·0139	1·0152	m	1·0202	1·0218
$21\bar{3}6$	w	0·9950	0·9955	wm	1·0012	1·0023
$31\bar{4}4$	w	0·9853	0·9858			(0·9921)
$20\bar{2}7$	w	0·9753	0·9765			(0·9834)
$10\bar{1}8$	wm	0·9437	0·9441	m	0·9505	0·9510
$31\bar{4}5$	wm	0·9211	0·9212	m	0·9269	0·9272
$21\bar{3}7$				w	0·9098	0·9098
$41\bar{5}0$				ms	0·9062	0·9061

† Intensities as in Table IIIa

ditions pertaining to these steels. Hence, although complete mutual solubility has been demonstrated for these phases in isolation,[4] the existence of two separate phases is quite general in steels containing Ti.

The TiC constituent does not play an important part in determining the properties or behaviour of the type of steel under investigation. A typical value of the lattice parameter for this constituent is 4·329 Å, similar to published values.[2, 3] In steels containing niobium, this cubic carbide was replaced by NbC which contained a small amount of TiC in solid solution (lattice parameter 4·431 Å). The other carbide-forming elements, especially vanadium, may dissolve partially in TiC.

Titanium Nitride (TiN)

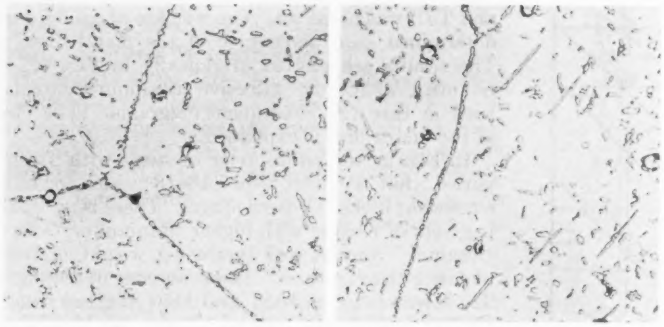
This constituent was present at all temperatures, but showed signs of beginning to dissolve in the matrix at 1150° C. Its presence at lower temperatures was masked by the considerable quantities of other constituents. In general TiN may be regarded as a non-metallic inclusion. A typical lattice parameter is 4·254 Å. Similar values have been obtained for this constituent in other steels.[2, 3]

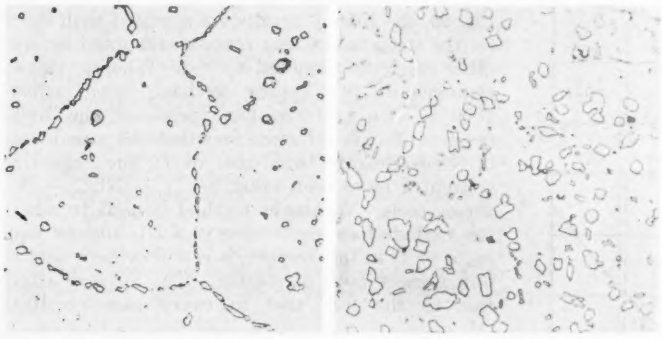
'Y Phase'

This phase is believed to be a second nitride of titanium, but its identity has not been fully established. In previous work by the authors (unpublished) with a number of different types of steel containing titanium, there could be varying amounts of particles visible under the microscope of the kind which are generally described as titanium nitride. X-ray examination showed that these could be justifiably represented by TiN + *Y* phase. It is believed that *Y* phase is either another modification of TiN or a nitride of different composition. It is also considered that *Y* phase can now be differentiated from TiN by its form and appearance under the microscope.

Unfortunately it has not been possible to obtain a residue containing only *Y* phase so that its identity could be fully established by chemical analysis. On the supposition that it is a nitride, attempts have been made to synthesize it; these have been unsuccessful. The interplanar spacings and a tentative hexagonal unit cell are given in Table III*a*.

(*a*) Fe_2Ti particles including plate like form; two steels after heat-treatment at 850° C
Steel 6 (1·15% Ti) Steel 17 (1·62% Ti)



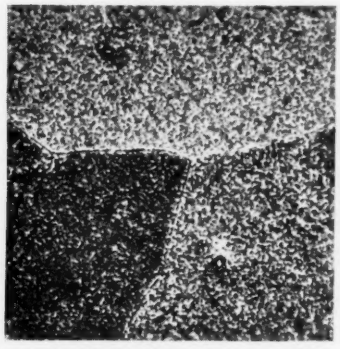


(*b*) Fe_2Ti at grain boundaries. Steel 27, 1050°C (1·04% Ti)

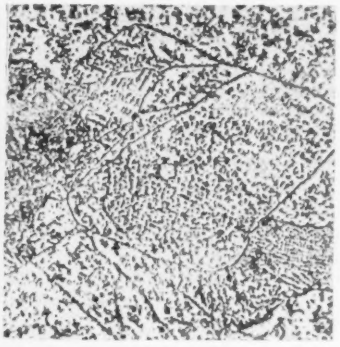
(*c*) Angular particles of Fe_2Ti. Steel 11 after heat-treatment at 850° C (3·17% Ti)

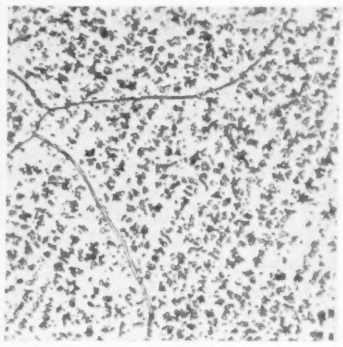
Fig. 7—Modes of occurrence of Fe_2Ti particles (Laves phase) × 750

(*a*) General precipitation of $M_{23}C_6$. Steel 7, 650° C (1·33% Ti) Steel 25 (1·07% Ti) Steel 36 (1·55% Ti)



(*b*) Precipitation of $M_{23}C_6$ in regular arrays; two steels at 650° C





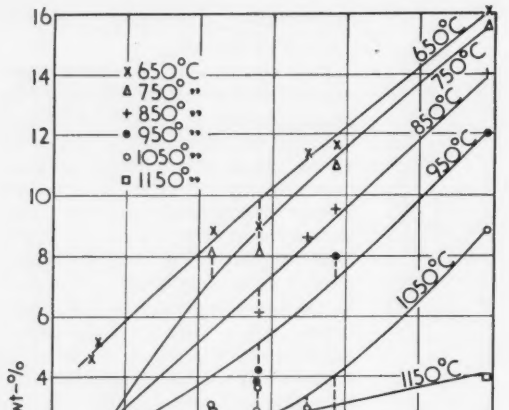
(*c*) Precipitation along sub-grain boundaries. Steel 3 (0·77% Ti) after 24 h at 625° C

Fig. 8—Modes of occurrence of the carbide $M_{23}C_6$ × 750

Intermetallic Compound 'Fe_2Ti' (Laves Phase)

This constituent can be precipitated at temperatures mainly in the range 750–950° C, but, depending on the total titanium content, need not all be taken into solution at temperatures up to 1150° C or above. When precipitated in the range stated the precipitate occurs in the form of plates (Fig. 7*a*), but when present as an equilibrium constituent at higher temperatures the phase occurs either as a grain-boundary constituent (Fig. 7*b*) or as particles occasionally somewhat angular in appearance within the grains (Fig. 7*c*).

X-ray data are given for two typical samples of this constituent in Table III*b*. The first of these is from a steel containing titanium, and the second from a steel containing niobium. Chemical analysis is appended for the first but not for the second, as the latter sample contained other constituents. The difference in lattice parameter indicates that niobium replaces titanium in solid solution. The constituent thus lies between Fe_2Ti and Fe_2Nb, although it also contains other elements in solid solution, as the chemical analysis indicates. These results may be compared with[1] those



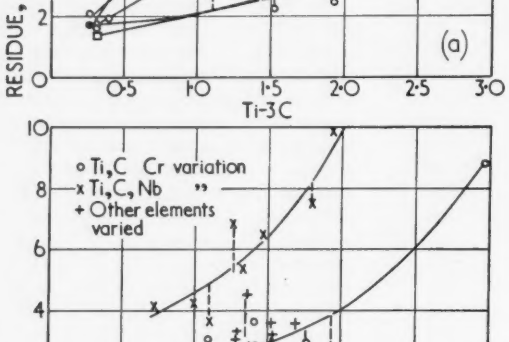


Fig. 9—Weights of residues separated for X-ray analysis: (*a*) Ti and C variation (including Nos. 16 and 18 with Cr variation; (*b*) weights at 1050° C with effect of Nb etc.

of VerSnyder and Beattie,[5] who assign the constituent a formula (Ti_{21},Mo_9) (Fe_{50},Cr_5Si_5). The composition of the first sample in Table III*b* is referred to in a footnote. It is similar, but not identical with the composition indicated by VerSnyder and Beattie.[5]

The Carbide $M_{23}C_6$ (*The ' κ ' Carbide*)

This carbide—$(Cr, Fe, Mo)_{23}C_6$ (with Cr/Fe approximately 2 : 1)—was stable at the lower temperatures of 550–750° C where it precipitated freely. It usually appeared in a plate-like form as indicated by the broadened X-ray reflections for certain sets of planes. By microscopical examination it was shown that this constituent precipitated in three main forms:

(i) A general precipitation throughout the grain accompanied by darkening of the microstructures (Fig. 8*a*)
(ii) Regular arrays of particles within the grains (Fig. 8*b*)
(iii) Precipitation along sub-grain boundaries (Fig. 8*c*).

The carbide redissolved rapidly on reheating to 1050° C or above.

In addition to the identification of these constituents by microscopical examination and X-ray residue analysis, an indication of the total amount of precipitated phases, and minor constituents (TiN, Y, and TiC) was obtained. The weights of residues were determined as a percentage of the metal dissolved. The results are plotted graphically in Fig. 9. The quantity Ti-3C, or ' effective titanium content,' is used in this and subsequent diagrams. (The choice of the factor of 3 is explained.)

In Fig. 9*a* the points refer to steels with Ti and C varied, but includes Nos. 16–18 which contained somewhat higher Cr percentages. There is an increasing bulk of residue with higher titanium or ' effective titanium ' content and increasing weight of residue at lower temperatures. The difference at the highest Ti content between 1050° and 1150° C arises from the Fe_2Ti which is still out of solution at 1050° C. In Fig. 9*b*, the 1050° C results are repeated with the data for the steels containing niobium (denoted by ×) and other elements (denoted by +). Whereas the other elements do not appear to have much effect at 1050° C, the niobium has increased the bulk of residue. To allow for the fact that the atomic weight of Nb is roughly twice that of Ti, the ' effective Ti contents ' have been taken as Ti + (Nb/2) − 3C for these steels. Whatever method is used to allow for the carbide-forming tendency of Nb and its equivalence to Ti in this respect, it is still evident that there is a greater bulk of residue. The authors attribute this to the fact that in every case at 1050° C,

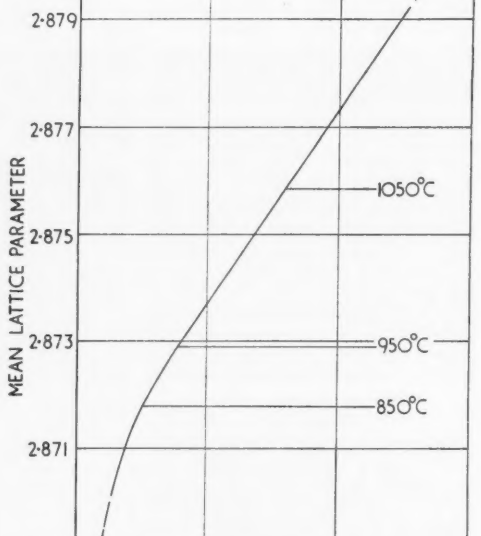


Fig. 10—X-ray lattice parameter measurements

Fe_2 (Nb,Ti) is left out of solution. Hence it is probably true to say that the Laves phase containing Nb has a lower solubility in the matrix.

Lattice Parameter Measurements

The results of the lattice parameter measurements on the ferrite matrix are shown in Fig. 10. The decrease in lattice parameter over the range 1150–750° C must be associated with decreasing solubility for the Laves phase (' Fe_2Ti ') with decreasing temperature. A further drop in parameter below 750° C is mainly the result of precipitation of $M_{23}C_6$.

Hardness Measurements

The general hardness measurements are not reported in full, but it is sufficient to observe that:

(i) Increasing solution temperature causes a slight increase in hardness due to increased solution of the titanium compound Fe_2Ti and to a lesser degree TiC (and TiN).

(ii) The precipitation of Fe_2Ti results in a slight decrease in hardness, indicating that although Fe_2Ti forms a plate-like precipitate the softening of the matrix, by removal of Ti, more than compensates for any precipitation hardening

(iii) The precipitation of $M_{23}C_6$ causes a considerable increase in hardness and is therefore an age-hardening constituent in this type of steel. In contrast with Fe_2Ti the amount of hardening must considerably exceed any softening tendency due to depletion of the solid solution concentration of alloy elements in the matrix.

A fuller investigation of precipitation-hardening characteristics showed how the effects of the two precipitants could be separated and assessed. Typical precipitation-hardening curves for one of the steels are shown in Fig. 11. In order to compare different steels, the maximum hardness change, the time for start of hardening, and the time to attain the maximum hardness were derived from each set of curves. The quantity $\Delta H_{max.}$ when plotted against titanium content for 550°, 650°, and 750° C gives, as in Fig. 12, a series of curves which show how there is a maximum increase in hardness at a titanium content which increases as the ageing temperature decreases. A higher level of hardness is reached at lower ageing temperature.

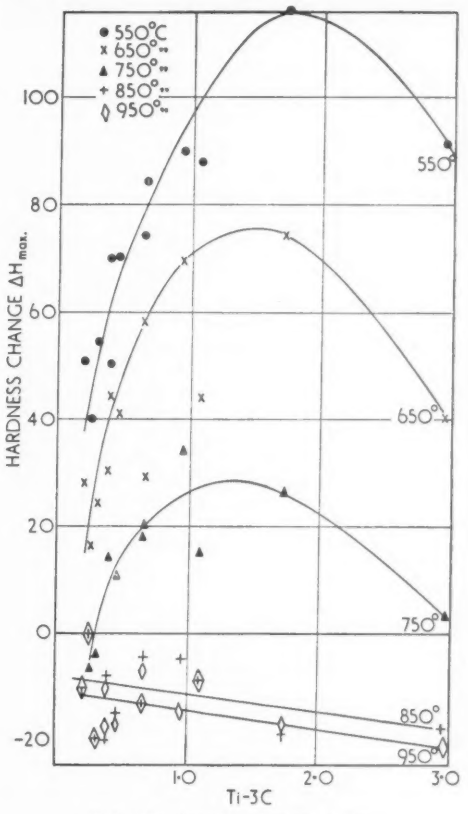


Fig. 12—Age-hardening data

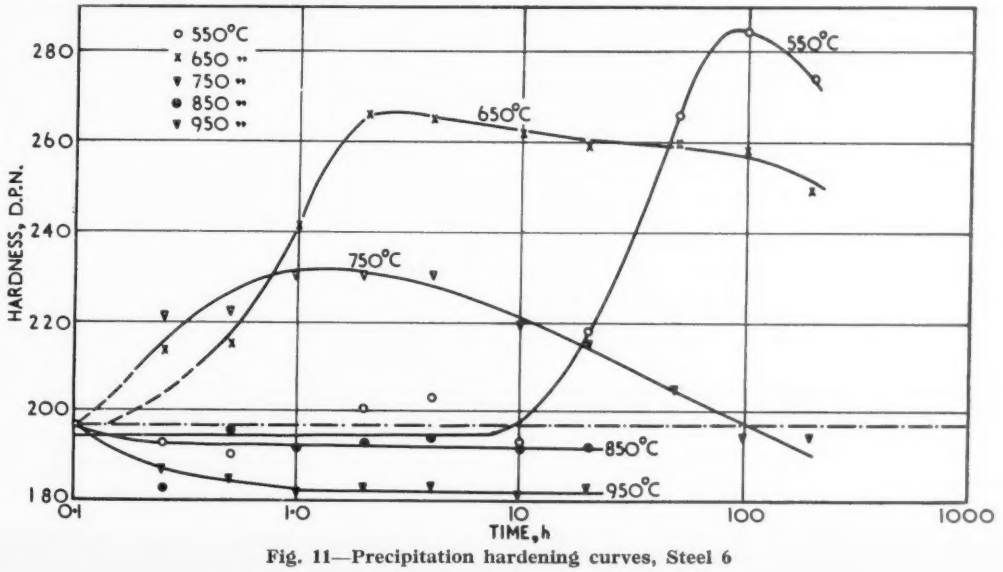


Fig. 11—Precipitation hardening curves, Steel 6

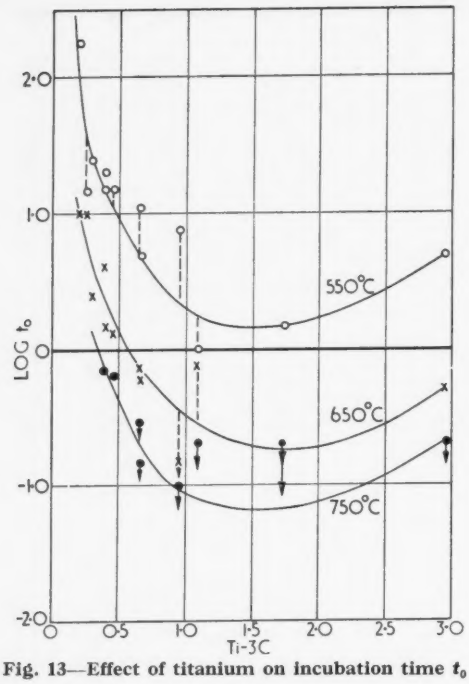


Fig. 13—Effect of titanium on incubation time t_0

In the precipitation-hardening range there is an incubation period represented by t_0 before which any appreciable hardening can be detected. These times are plotted against effective titanium content in Fig. 13. Increasing titanium lowers the time t_0 to a minimum beyond which further titanium additions do not result in an acceleration, but a slight retardation of the process. The time to maximum hardness shows a similar trend.

Effect of Rates of Cooling and Isothermal Heating on Precipitation Behaviour

Further information was gained about the precipitation behaviour of the two main precipitants, by cooling experiments and isothermal treatment of a commercial cast, the composition of which was based upon No. 6 in Table I. (Exact analysis: 0·07% C, 0·53% Mn, 0·85% Si, 0·035% S, 0·021% P, 0·19% Ni, 8·42% Cr, 2·89% Mo, 1·18% Ti.)

The results of the isothermal heating experiments are summarized in Fig. 14 which shows the times at different temperatures for the commencement of precipitation of Fe_2Ti and $M_{23}C_6$. The curve for the intermetallic compound completely hides the curve for $M_{23}C_6$ from the point of view of continuous cooling from temperatures above 950° C, with the result that although Fe_2Ti can form on continuous cooling, $M_{23}C_6$ does not.

The critical rate of cooling at which Fe_2Ti precipitates was also determined by plotting the amount of Fe_2Ti against rate of cooling as in Fig. 15. The critical rate is about 100° C/min measured over the range 1000–600° C.

Effect of Prior Structure on Creep Properties

To examine the effect of the precipitants upon the high-temperature strength, tests were carried out upon specimens of the commercial cast already referred to which had been heat-treated to produce different prior structures. The results are summarized in Table IV where the heat-treatment given is indicated, followed by the structure. The last column gives the time to rupture under a stress of 11 tons/in² at 625° C.

The data in Table IV clearly indicate the detrimental effect of starting with a structure containing Fe_2Ti and emphasize the beneficial effects of the ' κ ' carbide, showing that optimum rupture strength is favoured by some pre-precipitation of this phase at a temperature (550° C) lower than the testing temperature (625° C). The reason for the effect of Fe_2Ti is undoubtedly associated with a reduction in the solid solution strength. The beneficial effect of prior precipitation of carbide is presumably a result of a reduced tendency to over-ageing at the higher testing temperature by the finer dispersion of the pre-precipitated carbide particles. The somewhat lower ductility that accompanies this condition may, however, be considered to offset the increase in rupture time, whilst the best compromise is probably achieved by starting with a completely solution-treated condition and allowing the precipitate to form at the temperature of service.

INTERPRETATION AND DISCUSSION OF RESULTS*

The Presence of TiN, TiC, and *Y* Phase

The three constituents, TiC, TiN, and ' *Y* phase ' are present in all specimens and play only a minor role in the reactions affecting the properties of the material. TiN and ' *Y* phase ' may be regarded simply as non-metallic inclusions. TiC on the other hand does probably play a small part in that it may dissolve at lower temperatures if the carbon and/or titanium concentrations of the matrix are reduced considerably below equilibrium values.

In the present work a consistent interpretation of the structure and properties of these materials with respect to variations in composition has been achieved by the use of an ' effective titanium content ' derived

* To interpret more clearly the salient features of this work, the discussion of the results has been grouped under appropriate headings.

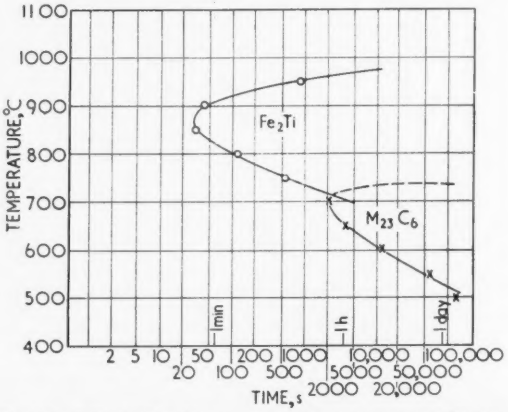


Fig. 14—Effect of isothermal treatment on precipitation of Fe_2Ti and $M_{23}C_6$

by subtraction of three times the carbon content from the titanium. This accounts for the fact that the solid-solution titanium is reduced by carbon, yet all the carbon is never combined as TiC, thereby leaving some in solution available for subsequent precipitation of $M_{23}C_6$.

Co-existence of TiC and $M_{23}C_6$

The occurrence of these two carbides implies that titanium is only partially effective as a 'carbide stabilizer.' This accords with previous experience in the authors' laboratory.

It is interesting to consider how TiC and $M_{23}C_6$ can co-exist at certain temperatures. Figure 16 shows diagrams in which $M_{23}C_6$ is represented by $(Cr,Fe)_{23}C_6$ which in the present series of steels contains Mo in solid solution. In a multi-component system equilibrium can readily involve three or more phases. Figure 16*a* is a triangle representing part of a complex phase diagram, e.g. it might have been cut out of the system Fe–Cr–Ti–C. This triangle shows how equilibrium is maintained between iron, $(Cr,Fe)_{23}C_6$, and TiC. It will be appreciated that in the full phase diagram the line *cd* lies on a surface extending above and below the plane in question and the point *e* becomes a line on this surface (cutting *cd* in *e*). The physical meaning of *cd* is that it represents the solubility of TiC and $(Cr,Fe)_{23}C_6$ in α-iron or alterna-

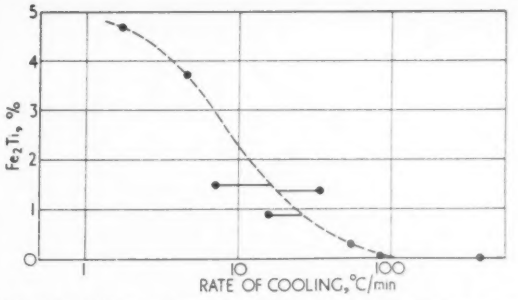
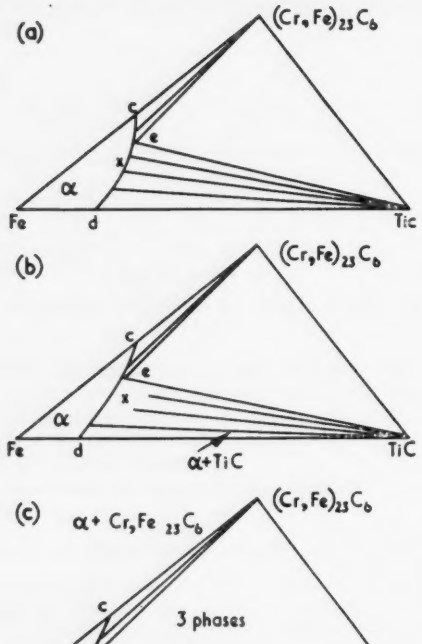


Fig. 15—Effect of rate of cooling on precipitation of Fe_2Ti

Table IV

EFFECT OF PRIOR STRUCTURE ON RUPTURE STRENGTH (COMMERCIAL CAST (0·07% C, 1·18% Ti) Creep tested at 11 tons/in² at 625° C

Initial Heat-treatment	Before or After Test	Microstructure: General Description	X-Ray Residue Analysis: Phases Present and Relative Amounts	X-Ray Residue Analysis: Wt.-% of Residue	Hardness $H_D/30$	Rupture Test Data: Time to Rupture, h	Rupture Test Data: Elongation, % (1 in.)	Rupture Test Data: Reduction in Area, %
1. 1050° C, ½ h, A.C.	Before	α + TiC + *Y* phase (and/or TiN) + trace of precipitate)	TiC (medium +) + *Y* phase (med. – amount)	3·11	187			
	After	As above + heavy carbide precipitate	TiC (med. +), Y (small) + $M_{23}C_6$ carbide (small)	4·27	252	538	11·2	59·2
2. 1050° C, ½ h, A.C. + 5 h, 850° C, A.C.	Before	α + TiC + *Y* phase + Fe_2Ti at grain boundaries and in plate form	Fe_2Ti large amount (obscures presence of TiC	5·65	188			
	After	As above + $M_{23}C_6$ precipitate. (Not generally as heavy as in previous case)	As above + trace TiC + trace $M_{23}C_6$	4·93	221	19	24·7	74·3
3. 1050° C, ½ h, A.C. + 20 h, 850° C, A.C.	Before	Similar to the previous	As previous sample	6·06	185			
	After	+ very slight general carbide precipitate	Insufficient $M_{23}C_6$ to detect	4·84	216	18	22·2	72·7
4. 1050° C, ½ h, A.C. + 1 h, 750° C	Before	TiC + *Y* + Fe_2Ti + possible $M_{23}C_6$ trace	Fe_2Ti med. amount, TiC med.	4·59	200			
	After	As above + carbide precipitate heavy in patches	As before but some $M_{23}C_6$ now present	5·88	225	23	29·4	78·0
5. 1050° C, ½ h, A.C. + 100 h, 750° C	Before	Similar to 1 h sample	Fe_2Ti large amount (TiC not detected	6·74	190			
	After	" " " " (little if any more $M_{23}C_6$ formed during creep testing)	Carbide not found in residue (insufficient)	5·83	206	3	29·8	69·9
6. 1050° C, ½ h, A.C. + 72 h, 550° C	Before	$M_{23}C_6$ at grain boundaries and within grains not fully precipitated	TiC, *Y*, and $M_{23}C_6$ (small plates	4·87	235			
	After	Heavy dense additional precipitate within grains	TiC (small medium amount) + $M_{23}C_6$ in plate form (medium amount)	5·38	256	651	3·1	9·9
7. 1050° C, ½ h, A.C. + 200 h, 550° C	Before	Heavy precipitate $M_{23}C_6$	$M_{23}C_6$ med., TiC small, *Y* small	7·57	279			
	After	" " "	$M_{23}C_6$ med., TiC small, *Y* very small	6·53	254	895	2·8	10·4



(*a*) Temperature T_1, all carbides in solution, X = fixed composition of a steel now in single phase region
(*b*) $T_2(< T_1)$ TiC precipitating. X now in two-phase region; lowering temperature shifts line *ced* towards Fe, and meanwhile *e* moves along *cd* to *d*
(*c*) $T_3(< T_2)$. X in three-phase region and $(Cr,Fe)_{23}C_6$ now precipitating

Fig. 16—Change in equilibrium conditions leading to change in carbide precipitation. Part of the system Fe–Cr–Ti–C

tively the solubility of carbon in an alloy ferrite. Assuming that Fig. 16*a* corresponds to a temperature at which for a given composition X both carbides are dissolved, then X lies inside the α region (shown here in the plane of the diagram). At lower temperatures (Fig. 16*b*) the line *cd* has moved towards the iron corner, so that the point X now lies in a region involving equilibrium between α and TiC. At lower temperatures, changes in the relative positions of *c*, *d*, and *e* can easily ensure that the point X is eventually enclosed in the three-phase region α + two carbides, as in Fig. 16*c*. This change in the equilibrium conditions could lead to some re-solution of TiC at lower temperatures; in fact at a sufficiently low temperature X might be found in the region for equilibrium between the matrix and $M_{23}C_6$ alone.

The possibility of re-solution of TiC can also be approached from another angle. Thus, equilibrium between TiC and matrix can be affected by the occurrence of both $M_{23}C_6$ in accordance with Fig. 16 and Fe_2Ti and an interpretation in terms of solubility relationships is possible. For the reaction:

$$\underset{\text{(matrix)}}{Ti} + C \rightleftharpoons \underset{\text{(precipitate)}}{TiC}$$

the product $[Ti][C] = k_1$ may be written. The precipitation of $M_{23}C_6$ could be regarded as reducing [C] in this equation so that more Ti and C are required in the matrix to restore the product to its correct value. Such a process would, of course, be slow at the temperatures involved and equilibrium would not be reached.

The precipitation of Fe_2Ti could likewise be governed by a relationship: $[Fe]^2[Ti] = k_3$ or $[Ti] = k_2$; when both reactions are in equilibrium $[C] = k_1/k_2 = K$. If after a fall in temperature Fe_2Ti precipitates rapidly it would follow that k_2 has decreased rather markedly; now k_1 will also have decreased but to a lesser extent because the precipitation of TiC is much less rapid than that of Fe_2Ti. If at the new temperature the constants are k_1', k_2', and K', it follows that initially $[Ti] > > k_2'$ but $\rightarrow k_2'$ as precipitation of Fe_2Ti proceeds. The product [Ti][C] tends to become rapidly too low, i.e. lower than k_1'. Alternatively $[C] < K'$. Hence, in spite of the fact that more TiC would precipitate by itself it has a tendency to partial re-solution due to depletion of Ti from the matrix by rapid precipitation of Fe_2Ti.

Solubility of Fe_2Ti and $M_{23}C_6$

From the lattice-parameter values in Fig. 10, it is clear that to a first approximation the lattice-parameter curve may be regarded as defining a solubility limit. The lattice parameters in the 'two-phase' region in Fig. 10 are approximately constant except at 650° C, where there is a rise towards higher titanium contents. This solubility limit refers to equilibrium between matrix and Fe_2Ti from 1150° to 750° C, but below 750° C equilibrium is with $M_{23}C_6$ although some Fe_2Ti may precipitate as well.

The solubility data derived from Fig. 10 are given in Table V and by plotting the logarithm of solubility against the reciprocal of the absolute temperature (Fig. 17) it seems probable that a change in slope occurs corresponding to the change in precipitation phenomena.

It was realised from marked differences in hardening characteristics corresponding to the two different precipitating phases that the temperature at which $M_{23}C_6$ began to form for a given steel could be derived from a graph of $\Delta H_{max.}$ against temperature. Two typical examples are shown in Fig. 18. The temperature of intersection of the two slopes denoted the maximum temperature of formation of $M_{23}C_6$.

The results from the combined X-ray and hardness data are summarized in the constitutional diagram in Fig. 19. From this diagram it is apparent that the

Table V

SOLUBILITY DATA FROM FIG. 10 FOR FIG. 17

Temp., °C	Absolute Temp. T° K	$\frac{1}{T} \times 10^4$	Solubility of Fe_2Ti	Log Solubility
650	923	10·83	* 0·10	0·00 −1
750	1023	9·77	0·24	0·380 ,,
850	1123	8·91	0·45	0·653 ,,
950	1223	8·18	0·82	0·914 ,,
1050	1323	7·56	1·55	1·190 ,,
1150	1423	7·03	2·85	1·455 ,,

* Equilibrium also involves $M_{23}C_6$

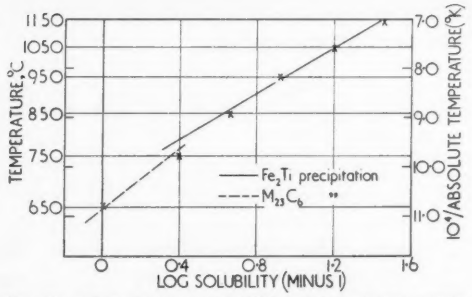


Fig. 17—Plot of log solubility data (Table VIII)

scatter of points from the hardness results is greater than from X-ray results, but an approximate mean curve is drawn to show the upper limit of $M_{23}C_6$ precipitation. In Fig. 19 matrix and TiC (+ nitride) co-exist in region I; region II corresponds to matrix and Fe_2Ti as well as TiC, etc. In region III $M_{23}C_6$ is an additional phase but there is some evidence that this region should be rather narrow, and there is another boundary below which only matrix + $M_{23}C_6$ co-exist (with TiC, etc.) and no Fe_2Ti is present. Thus reheating at 550° and 650° C of alloys containing Fe_2Ti out of solution has been found to give evidence of re-solution and, in any case, this phase does not appear to precipitate much below 700° C. The broken line in Fig. 19 is intended to suggest this possible further subdivision of the diagram III*b* in which only $M_{23}C_6$ is formed.

A diagram such as Fig. 19 may be regarded as a constitutional or precipitation diagram rather than an equilibrium diagram. It is drawn as a plane section of a complex system, and it follows that the composition of the matrix is not necessarily given by points on the curve bounding region I. It should be emphasized that the results of microscopical examination and X-ray phase identification are also in complete agreement with this diagram.

The Precipitation of $M_{23}C_6$

Not only can $M_{23}C_6$ be precipitated in steels containing titanium for the reasons described, but also the rate of formation of $M_{23}C_6$ appears to be more rapid with increasing titanium contents (*see* Fig. 13). To explain this phenomenon it is necessary to assume that if the ultimate amount of $M_{23}C_6$ is increased,

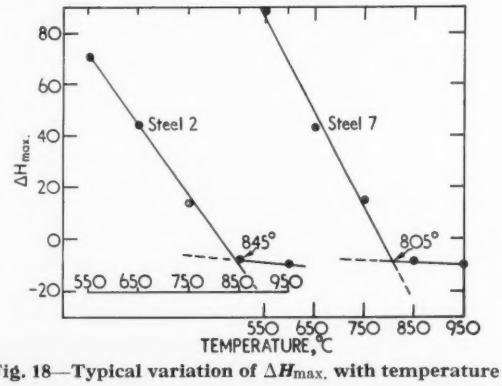


Fig. 18—Typical variation of $\Delta H_{max.}$ with temperature

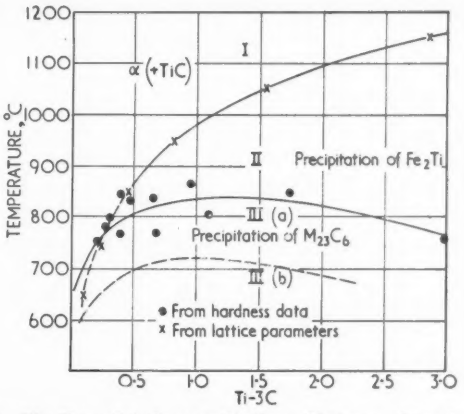


Fig. 19—Completed constitution diagram based on hardness and X-ray data

the initial rate of formation will be more rapid in accordance with a higher degree of supersaturation. It appears that increasing titanium content actually *increases* this degree of supersaturation, in spite of the supposed affinity of titanium for carbon. That titanium should act in this way is suggested by the diagram in Fig. 19.

The solubility of Ti in Fe is much smaller than that of Cr so that in considering the equilibrium between ferrite and $M_{23}C_6$, the addition of titanium tends to cause the composition of the matrix to move in the direction shown in Fig. 20. As a result the tie lines between ferrite and $M_{23}C_6$ are cut at positions corresponding to increasing proportions of $M_{23}C_6$ relative to ferrite, with the observed effect upon the precipitation characteristics. Figure 20 in fact represents another aspect of the multicomponent system of which Figs. 16 and 19 describe other features.

Further aspects of the effect of titanium upon the precipitation of $M_{23}C_6$ may be suggested in terms of an activation energy Q related to the times t_0 by the equation:

$$t_0 = ke^{-Q/RT};$$

Q so defined, increased with increasing titanium content, but k decreased. Neither relationship was linear,

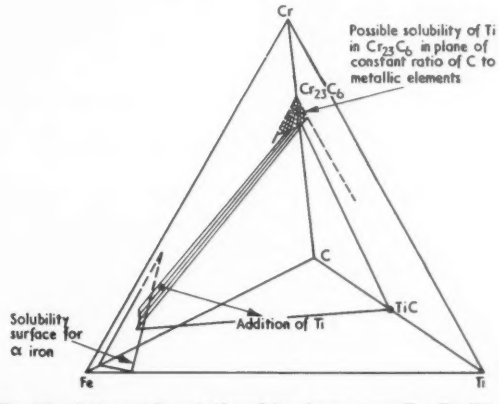


Fig. 20—Schematic relationships in system Fe–Cr–Ti–C

Table VI

STRESS-RUPTURE RESULTS—EXPERIMENTAL STEELS

Stress: 11 tons/in² **Bar Material**
Test Temperature: 625° C (1157° F) **Heat-treatment: 1050° C, ½ h, A.C.**

Steel No.	1	2	3	4	5	6	7	8	9	10	11
Rupture life, h	39·6	64·9	90·0	142·1	472·0	1127·2	1442·5	1625·0	1244·9	1292·4	583·5
Elongation on 1 in., %	26·9	18·4	13·5	17·7	13·3	13·8	6·1	13·6	17·9	7·2	13·8
Reduction in area, %	81·3	83·1	80·6	80·4	72·5	66·6	32·8	70·0	76·0	32·9	63·5
Composition variable*	Titanium										

Steel No.	12	13	14	15	16	17	18	19	20	21	22
Rupture life, h	42·6	22·9	24·2	19·2	288·1	71·7	1012·9	20·2	108·8	108·1	1735·7
Elongation on 1 in., %	20·6	20·9	21·7	24·5	12·8	22·8	15·9	21·6	20·1	20·0	5·7
Reduction in area, %	76·9	77·2	78·5	80·4	65·5	77·4	71·3	83·5	71·2	71·8	39·6
Composition variable*	Carbon				Chromium			Molybdenum and Titanium			

Steel No.	23	24	25	26	28	29	29	30	31
Rupture life, h	141·6	118·3	623·2	1030·0	893·5	95·1	96·9	1442·5	1135·0
Elongation on 1 in., %	19·3	19·9	13·3	12·0	7·4	24·4	32·2	6·1	14·2
Reduction in area, %	75·3	72·5	65·3	60·0	29·0	75·4	76·2	32·8	78·8
Composition variable*	Niobium and Titanium							W and Ti	V and Ti

Steel No.	32	33	34	35	36	37	38	39
Rupture life, h	43·9	278·7	381·6	85·5	104·5	17·5	46·0	446·6
Elongation on 1 in., %	23·7	18·1	18·6	26·1	23·6	18·6	27·7	12·3
Reduction in area, %	81·6	80·5	75·4	75·8	77·0	82·4	77·0	52·0
Composition variable*	Cr and Ti	Al and Ti		Al, Mo, and Ti		Nb, Mo, and Ti		Nb, V, W, and Ti

* Relative to 0·04–0·10% C, 8% Cr, 3% Mo base composition

but the variation shown again reflected the fact that higher titanium content actually favoured the precipitation of $M_{23}C_6$ by lowering the time t_0 in a regular manner (cf. Fig. 13). At the comparatively low temperatures at which $M_{23}C_6$ precipitates it might be expected that the diffusion of carbon would be the controlling factor rather than the much slower diffusion of alloy elements. Towards higher Ti contents the value of Q did in fact approach the value for diffusion of carbon. There is, however, considerable doubt whether valid conclusions can be drawn on the amount of information available at present.

The considerable degree of age-hardening associated with the precipitation of $M_{23}C_6$ could be due to either dispersion hardening, i.e. hardening by numerous small particles embedded in the matrix, or to coherency hardening which is caused by the stresses at coherent interfaces between matrix and precipitate particles. The appearance of the X-ray photographs in showing a plate-like form of the precipitate would support the

view that the second type of hardening is predominant at least in the early stages of precipitation. Relief of the coherency stresses occurs in time and over-ageing follows as in Fig. 11. Longer times of heating would be expected to give coagulation of carbides and a more globular form.

The possibility of coherency hardening by $M_{23}C_6$ suggests certain crystallographic relationships. It is almost a matter of convention to look for similar layers of atoms in the respective structures. Such a similarity is exemplified by the well known equivalence of {111} planes in austenite with {110} planes in ferrite (Figs. 22*a* and *b*). In Fig. 22 similar layers in the structures of $M_{23}C_6$ and Fe_2Ti are also shown for comparison. Certain atoms have been purposely omitted in Figs. 22*a* and *b* in order to suggest the resemblance to the layer shown in Fig. 22*c*. In the present case precipitation is from a ferrite lattice, and it will be clear that there is a close similarity between the corresponding layers although a small angular adjustment and some differences in linear dimensions are involved. Such a diagram as Fig. 22 only represents the starting point for a full treatment of the crystallography of the precipitation of these phases. The rapid precipitation of Fe_2Ti itself, and its platelike mode of formation (Fig. 7*a*) justifies the belief that the crystallographic similarity is important in this case. (Fig. 22*d*.)

Solid-solution Hardening by Titanium

Although it is not considered necessary to report all of the large number of hardness measurements,

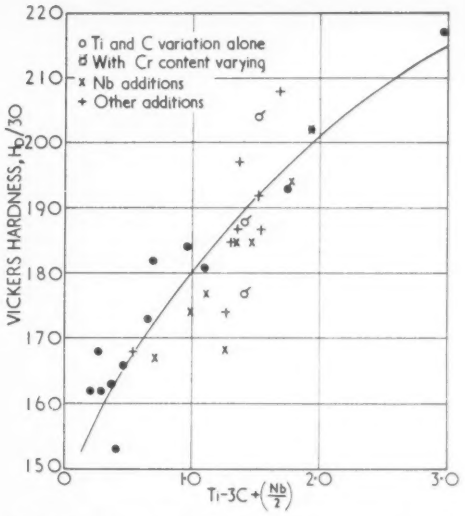


Fig. 21—Hardness of steels solution-treated at 1050° C

Fig. 21 represents some of these measurements and draws attention to the solid-solution hardening effect of titanium. This diagram refers to solution treatment at 1050° C when most of the titanium is in solid solution. The trend is clearly in agreement with the conclusion that titanium does cause appreciable solid-solution hardening. Certain points which lie above the curve refer to the steel of highest chromium content

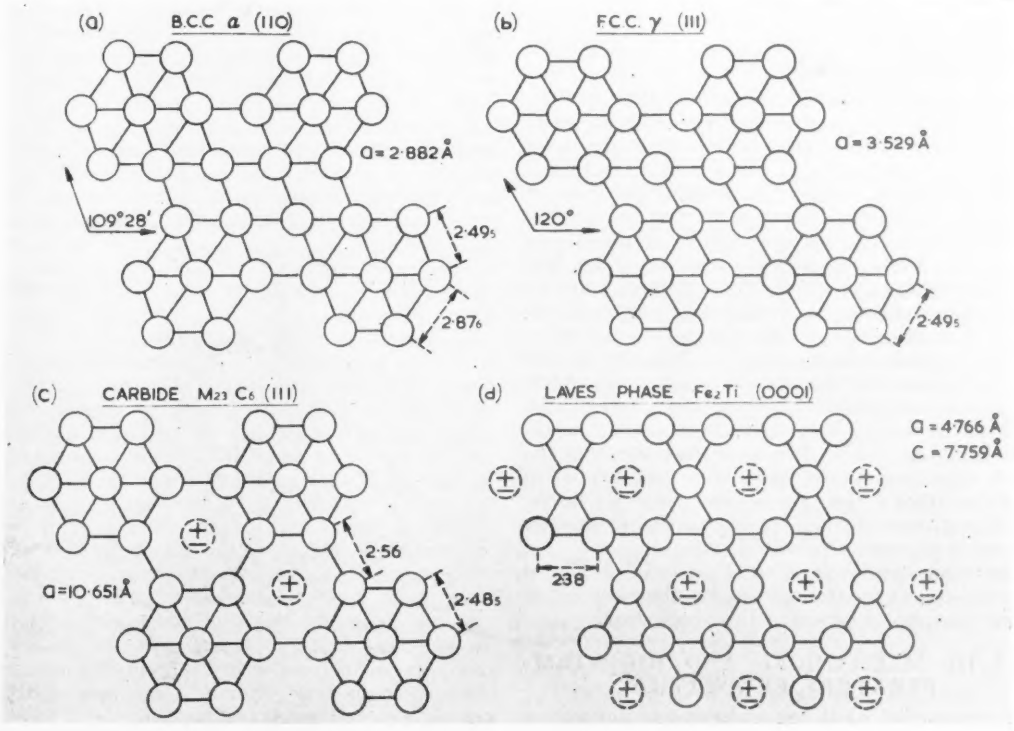


Fig. 22—Similar layers of atoms in four different crystal structures

Table VII—SCALING RESISTANCE

Steel No.	Analysis, %						Gain in Weight mg/cm², in 500 h			
							Flue Gas			Steam
	C	Mn	Si	Cr	Mo	Ti	566° C (1050° F)	600° C (1112° F)	630° C (1166° F)	630° C (1166° F)
40	0·06		0·65	8·10	3·16	...	7·0	10·8	13·9	14·5
6	0·06	0·55	0·68	7·92	3·20	1·15	6·1	10·4	12·9	11·3
8	0·04	0·60	0·56	7·60	3·10	1·39	5·8	9·9	...	...
9	0·07	0·51	0·69	7·91	3·12	1·95	5·6	7·6	10·6	10·0
11	0·07	0·50	0·82	8·15	3·12	3·17	4·0	7·8	9·2	8·7
1% Cr–½% Mo tube steel	0·07	0·42	0·53	0·82	0·56	...	10·0	...	34·0	32·5

(No. 18) and to two steels containing 1·5 and 1·8% aluminium respectively (Nos. 36 and 34). Thus there is evidence here of a small additional solid-solution hardening effect due to these elements.

The atomic diameter of titanium is larger than that of iron by about 15%. It is thus on the borderline of the 'favourable size factor'.[6] Any titanium atoms in solid solution therefore cause a considerable degree of lattice strain. This is reflected in the higher hardness of steels in which as much titanium as possible is kept in solid solution by quenching from solution temperatures, and by the considerably higher mean lattice parameters of alloys in this condition compared with alloys in which Fe_2Ti has been precipitated. It is also likely that a contribution to the hardness of the lattice arises from clustering of titanium atoms especially near to the solubility limit at equilibrium or with increasing supersaturation on quenching.

Effect of Niobium, Tungsten, Vanadium, and Aluminium

Table II dealing with the constitution of the alloys shows that the general phenomena which have been described are not markedly affected by the addition or substitution of niobium, vanadium, tungsten, or aluminium, within the composition limits chosen. The solubility limits are not affected by tungsten and aluminium, but the former element may enter into the carbide phase. Niobium does, however, have an effect on the solubility and composition of the Laves phase. It replaces some of the titanium in this phase and also replaces titanium in TiC—a fact which has been taken account of in Figs. 9 and 21. The effects of titanium and niobium are not simply additive on a weight-for-weight basis, but may be more nearly so on an atomic basis. It is clear, however, that the Laves phase containing niobium is less soluble in ferrite at 1050° C than the similar phase containing titanium without niobium. It appears that aluminium also tends to reduce this solubility.

Increasing chromium up to 14% (steels 16, 17, 18) does not appear to alter appreciably the composition of the precipitated phases or their behaviour.

Part III—MECHANICAL AND HIGH-TEMPERATURE PROPERTIES

The properties which are considered in this section of the paper refer, in the first instance, to stress-rupture tests made upon 39 experimental steels listed in Table I, augmented by scaling tests made upon four of these steels, one further experimental 8% Cr steel, and a 1% Cr–½% Mo tube steel. The remainder of the section is concerned with tests made upon two casts of a steel of a composition (patent applied for) based on the experimental data and the metallurgical features discussed in Part II of this paper.

EXPERIMENTAL STEELS

Experimental Procedure and Results

In assessing the high-temperature properties of steels it is convenient to adopt as a first step a selective test criterion related to the prospective industrial application, and to make more comprehensive tests upon one, or several, of the more promising steels. In this instance the steels detailed in Table I were tested to rupture at 625° C (1157° F) under a stress of 11 tons/in², each of the 39 steels being in the 1050° C, A.C. condition. The results are given in Table VI.

The scaling resistance of several 8% Cr, 3% Mo steels was determined by making tests in a flue-gas atmosphere at 566°, 600°, and 630° C (1050°, 1112°, and 1166° F) and in steam at 630° C. The results of these tests are given in Table VII, with data for a

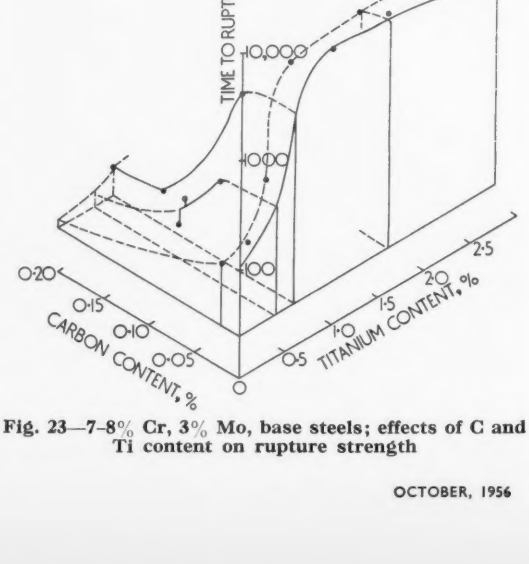


Fig. 23—7–8% Cr, 3% Mo, base steels; effects of C and Ti content on rupture strength

Table VIII—PHYSICAL PROPERTIES

(*a*) **Thermal Expansion**

Steel Quality	2¼% Cr–1% Mo	8% Cr–Mo–Ti	18/12/1	Steel Quality	2¼% Cr–1% Mo	8% Cr–Mo–Ti	18/12/1
Temperature, ° F	Mean Coefficient per ° F × 10^6			Temp., ° C	Mean Coefficient per ° C × 10^6		
68–200	...	5·45	9·10	20–100	...	9·85	...
„ –400	6·70	5·95	9·35	„ –200	12·0	10·70	16·70
„ –600	7·10	6·28	9·65	„ –300	12·7	11·25	17·35
„ –800	7·40	6·55	9·90	„ –400	13·1	11·70	17·70
„ –900	7·50	6·70	10·05	„ –500	13·6	12·15	18·15
„ –1000	7·60	6·80	10·20	„ –600	14·0	12·45	18·55
„ –1100	7·75	6·93	10·35	„ –650	14·2	12·65	18·80
„ –1200	7·85	7·03	10·45				

(*b*) **Modulus of Elasticity**

Steel Quality	2¼% Cr–1% Mo	8% Cr–Mo–Ti	18/12/1	Steel Quality	2¼% Cr–1% Mo	8% Cr–Mo–Ti	18/12/1
Temperature, ° F	Tons/in²			Temp., ° C	Tons/in²		
68	13,700	13,950	13,200	20	13,700	13,950	13,200
200	13,450	13,650	12,750	100	13,500	13,680	12,750
400	13,100	13,250	12,150	200	13,150	13,250	12,150
600	12,450	12,800	11,500	300	12,600	12,850	11,650
800	11,750	12,300	10,850	400	12,000	12,400	10,950
900	11,450	12,000	10,550	500	11,350	11,900	10,450
1000	10,850	11,600	10,250	600	...	11,100	9850
1100	...	11,100	9900	650	...	10,600	9600
1200	...	10,600	9600				

1% Cr–½% Mo tube steel, scaled in a flue-gas atmosphere at 566° and 630° C and in steam at 630° C.

Discussion of Results

The steels of most direct interest, Nos. 1–15 inclusive in Table I, had a 7–8% Cr, 3% Mo base and variable titanium and carbon contents. Their rupture strengths are shown in Fig. 23 as a combined function of carbon and titanium contents. This diagram illustrates the beneficial effect conferred by titanium upon the rupture strength. The detrimental influence of carbon can be attributed to its action in removing titanium from solid solution in the ferrite as TiC and thus reducing the ' effective titanium ' content which by solution hardening of the ferrite and its influence upon the precipitation of the $M_{23}C_6$-type carbide appears to be a major factor in producing creep resistance.

The remaining steels were tested with the object of judging the effect of other elements upon the rupture strength. The addition of chromium (steels 16, 17, and 18), in general confirmed the results of preliminary work (Fig. 5), showing it to be deleterious to the rupture strength. The result for steel 18 was, however, anomalous in this respect. Reduction in molybdenum content to 1% (steels 19, 20, and 21), appreciably lowered the rupture strength, whilst increasing molybdenum to 4% (steel 22), produced the best rupture life under these test conditions shown by any of the 39 experimental steels. The improvement relative to that shown by steels containing 3% Mo was not considered sufficient to justify the addition of a further amount of this expensive alloying element. Combined additions of niobium and titanium were examined (steels 23–29 inclusive), and showed niobium to be an inadequate replacement for titanium, although its presence in amounts up to about 0·9% did not seem to reduce the rupture strength, provided sufficient titanium had been added to the steel. It is probable that this detrimental effect of niobium is due to its part, when present in sufficient amount, in reducing the solubility of Fe_2Ti at 1050° C, thus lowering the ' effective titanium ' in solid solution and reducing the high-temperature strength of the ferrite.

The addition of 0·76% tungsten (steel 30), appears to have no marked strengthening influence and it might be presumed to act in the same way as molybdenum to which it bears many similarities as an alloying element. The same remark might be made regarding the addition of vanadium to steel 31. The influence of aluminium has been examined in steels 33, 34, 35, and 36; this element appears to be detrimental in its action, probably for the same reason as niobium, i.e. by reducing the Fe_2Ti solubility at 1050° C, although the mechanism is more by virtue of its preferential solid solution in the ferrite than by compound formation. The combined addition of niobium, vanadium, and tungsten (steel 39) resulted in some reduction in rupture strength, probably due to the already mentioned influence of niobium.

The results of the scaling tests (Table VII) confirmed that the scaling resistance of 8% Cr–3% Mo steels in steam and flue gas at 630° C was of a similar order to that exhibited by 1% Cr–Mo tube steel at 566° C in a flue-gas atmosphere, thus rendering such materials suitable for service in the temperature range 566–621° C (1050–1150° F) as far as resistance to scaling is concerned.

As an outcome of these results it was decided to concentrate further work on casts of 8% Cr–3% Mo steels containing not more than 0·1% C and between

Table IX
MECHANICAL PROPERTIES—BAR MATERIAL

Steel Quality	2¼% Cr–Mo	8% Cr–Mo–Ti			18/12/1	8% Cr–Mo–Ti	2¼% Cr–Mo*	8% Cr–Mo–Ti	18/12/1	2¼% Cr–Mo*	8% Cr–Mo–Ti	18/12/1	8% Cr–Mo–Ti	18/12/1
Test temperature, °C °F		20 68				500 932		550 1022			600 1112		650 1202	
Cast No.		B6860				B6860		B6860			A30292		A30292	
Ultimate tensile stress, tons/in²	32·6	35·9	51·8	40·0	43·9	36·8	31·8	24·0	29·9	27·1	19·5	26·8	25·2	21·6	22·5
Proof stress, tons/in²: 0·2%	...	25·7	...	...	...	13·4	16·6	...	16·1	11·5	...	...	12·0	...	9·2
0·1%	15·3	24·7	...	...	...	12·5	15·7	11·2	15·3	10·9	10·0	...	11·7	...	9·4
Limit of proportionality, tons/in²	5·0	17·0	...	...	...	6·4	10·6	5·0	11·3	6·4	4·3	...	6·4	...	5·3
Elongation on $4\sqrt{a}$, %	40·0	6·4	2·0	9·5	8·0	59·0	29·6	40·0	26·4	37·0	58·0	25·6	42·0	28·0	54·0
Reduction in area, %	53·0	9·0	...	12·0	8·4	72·0	60·2	76·0	57·9	63·0	83·0	59·0	64·0	64·5	66·7
Heat-treatment	Annealed 930° C	1050° C, A.C.	1050° C, A.C.; 550° C, 100 h, A.C.	1050° C, A.C.; 650° C, 3 h, A.C.	1050° C, A.C.; 850° C, 1 h A.C.	1050° C, A.C.	1050° C, A.C.	Annealed 930° C	1050° C, A.C.	1050° C, A.C.	Annealed 930° C	1050° C, A.C.	1050° C, A.C.	1050° C, A.C.	1050° C, A.C.

* Interpolated values

1% and 1½% Ti. The remainder of this paper deals with tests made upon a 5 cwt and a 12 cwt high-frequency cast of this composition.

COMMERCIAL STEELS

Experimental Procedure and Results

More extensive tests have been made upon bar and tube manufactured from one or other of the following casts:

Cast No.	Manufacturing Method	C, %	Mn, %	Si, %	S, %
A.30292	High-frequency, 5 cwt	0·07	0·53	0·85	0·035
B.6860	High-frequency, 12 cwt	0·07	0·68	0·75	0·036

	P, %	Cr, %	Mo, %	Ti, %
A.30292 High-frequency, 5 cwt	0·021	8·42	2·89	1·18
B.6860 ,, ,, 12 cwt	0·024	8·60	3·08	1·45

Physical Properties

The thermal expansion and modulus of elasticity values for cast B.6860 have been determined in the temperature range 20–650° C (68–1200° F) and are given in Table VIII with similar data for a 2¼% Cr–1% Mo ferritic steel and a 18/12/1 Cr–Ni–Nb austenitic steel, representative respectively of creep-resisting steels capable of being used at temperatures up to 566° C (1050° F) and 663° C (1225° F) for long-life service in steam power plant.

Mechanical Properties

Tensile tests were made on bar material of both casts in the 1050° C, A.C. condition at temperatures up to 650° C: room-temperature tensile tests were also carried out on cast B.6860 reheated for various times at 550°, 650°, and 850° C respectively after solution treatment at 1050° C. The treatment at 550° and 650° C was intended to precipitate $M_{23}C_6$, and that at 850° C to precipitate Fe_2Ti. The results of these tests are given in Table IX, with comparative data at 20°, 550°, 600°, and 650° C for the 2¼% Cr–Mo and 18/12/1 Cr–Ni–Nb materials.

Low-deformation Creep Resistance

Creep tests have been carried out on bar material from cast B.6860 under a stress of 3 tons/in² at 600°, 625°, 650°, 675°, and 700° C (1112°, 1157°, 1202°, 1247°, and 1292° F) with the results shown in Fig. 24 on a temperature/time basis. The apparent inconsistency of the relationship for 0·1% plastic strain is considered later in discussion of these and other results.

Rupture Strength

Rupture tests have been made on bar material of both casts in the 1050° C, A.C. conditions; specimens from cast B.6860 were tested at 566°, 593°, and 621° C (1050°, 1100°, and 1150° F) and specimens from cast A.30292 at 625° and 649° (1157° and 1200° F). Tests have also been made upon tube samples of cast A.30292 in the 'as extruded' and 1050° C, A.C. conditions at 625° C (1157° F). All these data are given in Table X.

Cold-drawing Trials

Cold-drawing trials have been made using two 4½-in. dia. × 20 in. billets of cast A.30292. These were pierced at 1250° C and pilgered to form 2¾ in. dia. × ⅜ in. thick hollows. Based upon the results of reverse bend tests, an anneal-

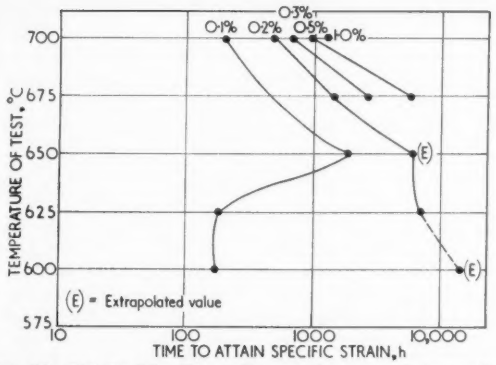


Fig. 24—8% Cr–Mo–Ti quality steel; stress 3·0 tons/in²

ing temperature of 850° C was used before each cold-drawing pass. This treatment, 1 h at 850°C, had the effect of precipitating Fe_2Ti from solid solution and making the steel more readily workable. The hollows were reduced in five passes to 2 in. outside dia. × 1½ in. internal dia. The procedure before each pass was to anneal at 850° C for 1 h, pickle and lead-coat the tube, cold-draw, then remove the lead coating. It was found essential to use lead as the lubricant, less efficient lubricants such as soap breaking down during drawing.

Weldability

Welding tests have been made using tube material from cast A.30292. Flash butt welds, oxy-acetylene welds, and arc welds were made and bend tests carried out on them after various post-welding treatments. The flash butt welds were made between 8% Cr–Mo–Ti tubes whilst the oxy-acetylene and arc welds were made between the 8% Cr–Mo–Ti tube and a 1% Cr–½% Mo tube steel.

Discussion of Results

The difference in thermal expansion of conventional ferritic (e.g. 2¼% Cr–Mo) steels and austenitic qualities is about 30%; the thermal expansion characteristics of the 8% Cr–Mo–Ti steel (Table VIII) are about 10% below those of the 2¼% Cr–Mo steel now being used in steam plant for service up to metal temperatures of 566° C (1050° F). In consequence the high stresses brought about by austenitic-ferritic junctions would

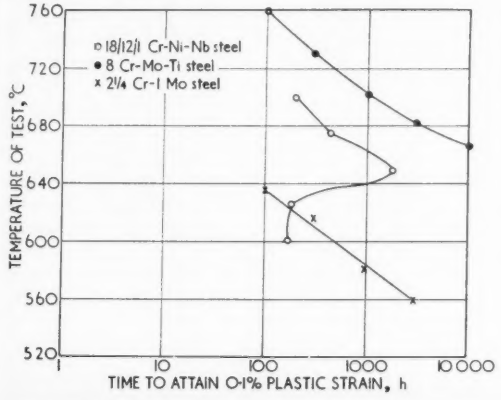


Fig. 25—Stress 3·0 tons/in²: 0·1% plastic strain

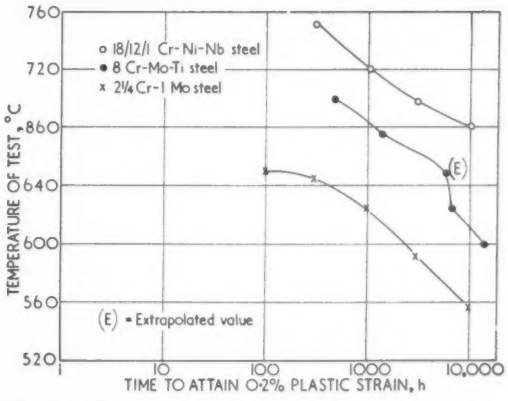


Fig. 26—Stress 3·0 tons/in²: 0·2 % plastic strain

be appreciably reduced by the use of the intermediate chromium steel in place of austenitic material.

The mechanical properties of the 8% Cr–Mo–Ti steel in the 1050° C, A.C. condition (Table IX), apart from rather lower ductility, are similar to those of the 18/12/1 steel at room temperature, 550°, 600°, and 650° C, and somewhat superior to those of the 2¼% Cr–Mo steel at these temperatures. The room-temperature tensile strength of the 8% Cr–Mo–Ti steel was increased by tempering treatments of 3 h at 650° C and 1 h at 850° C, which would precipitate $M_{23}C_6$ and Fe_2Ti respectively. A prolonged treatment of 100 h at 550° C did produce a significant increase in tensile strength to 51·8 tons/in² but this was accompanied by very low ductility, both features being attributed to the fine dense precipitation of $M_{23}C_6$ carbide known to occur under these conditions. This latter test was made primarily with a view to the use of such an intermediate chromium steel for applications demanding a cold tensile strength of over 50 tons/in² but it was evident that the accompanying low ductility precluded such a possibility.

The creep-deformation behaviour of this steel under a stress of 3 tons/in² and various temperatures (Fig. 24) reveals an anomalous curve shape for the 0·1% plastic-strain line in that the time to attain this amount of deformation is nearly identical at the two test temperatures of 600° and 625° C, 170 and 180 h respectively, and *less* than that at the higher temperatures of 650°, 675°, and 700° C when 1800, 426, and 194 h were required to reach this level of deformation. The anomaly has begun to disappear at the 0·2% plastic-strain level and the explanation for it is believed to lie in the precipitation of the $M_{23}C_6$ carbide. Reference to the precipitation-hardening characteristics discussed in Part II of this paper will show that at temperatures of 650° and 700° C this carbide would be mainly precipitated before the stress could be applied in the creep tests in question. At the lower temperatures of 625° and 600° C, however, this precipitation would be much less developed in the time elapsed before loading the test-piece and in consequence the transient, or first-stage, creep at these lower temperatures could proceed without the 'keying' action which such a precipitation would be expected to cause. The result of this behaviour is apparently

Table X—8% Cr–Mo–Ti QUALITY STEEL—STRESS-RUPTURE RESULTS (COMMERCIAL STEELS)

(i) Bar Material: 1050° C, ½ h, A.C.

Cast No.	B.6860*							A.30292*					B.6860			
Temperature of test, °C / °F	566 1050				593 1100			621* 1150				625 1157					649* 1200			
Stress, tons/in²	14·0	15·0	16·0	17·0	13·0	14·0	15·0	5·0	7·0	9·0	11·0	8·0	10·0	11·0	12·0	13·0	3·0	5·0	7·0	9·0
Time to rupture, h	3021†	1172	81	15	2837	2554	213	7655†	3826	3894	492	5331	1308	462	549	48	7397†	6430	1182	216
Elongation on 1 in., %	...	18·4	19·6	28·7	11·6	11·9	14·9	...	10·1	10·7	11·0	13·8	14·4	15·0	12·4	20·9	...	11·9	10·7	11·3
Reduction in area, %	...	68·0	65·5	62·0	39·2	43·6	68·6	...	...	...	...	69·2	71·8	81·2	63·9	77·5	...	...	...	...

* Tests carried out by Babcock and Wilcox Ltd. † Unbroken

(ii) Tube Material: Test Temperature 625° C (1157° F)

Cast No.	A.30292										
Material Condition	As Extruded					Heat-Treated 1050° C, ½ h, A.C.					
Stress, tons/in²	10·0	11·0	12·0	13·0	14·0	6·0	8·0	10·0	11·0	12·0	13·0
Time to rupture, h	3086	588	84	18	2	10,000*	3210	1000	612	232	251
Elongation on 1 in., %	12·2	12·3	20·8	21·3	22·6	...	13·9	11·7	13·8	15·7	15·2
Reduction in area, %	74·0	71·8	75·8	76·5	74·6	...	69·2	62·3	73·5	71·8	71·2

* Unbroken

only obvious at comparatively low deformation levels and, as these data indicate, is masked when greater amounts of creep are being considered.

Apart from its academic interest this behaviour is worth recording as an argument against the use of such low-strain criteria as an assessment of long-time creep strength since there is considerable evidence that in single-phase materials exemplified by this steel, and more commonly by austenitic alloys, such occurrences are by no means unusual. The temperature/time curves for the 8% Cr–Mo–Ti steel and the 2¼% Cr–Mo ferritic steels and 18/12/1 Cr–Ni–Nb austenitic steel are given in Figs. 25 and 26 for a stress of 3 tons/in² and 0·1% and 0·2% plastic strain respectively. These diagrams both illustrate the comparative strengths of these materials and, together with the rupture test figures given below, emphasize the points referred to in the preceding discussion.

The rupture test results (Table X) outline a notable feature of this steel, namely its good level of rupture ductility. The lowest rupture elongation obtained was 10·1% for a test at 610° C (1130° F) which fractured in 3826 h. This behaviour was common to bar material and to tube, the latter being tested in the heat-treated and extruded conditions. The tests on tube were made on specimens cut from the tube wall, the tube dimensions being 2 in. outside dia. × ¼ in. wall.

It is important to know the strength of a steel in relation to that of the materials capable of being used at temperatures immediately above and below its intended operating range, 566–621° C (1050–1150° F) in the instance of this intermediate chromium material. This is already indicated in Figs. 25 and 26; the following comparison is made on the basis of the stress to cause rupture in 3000 and 10,000 h at 625° C (1157° F):

Quality	2¼% Cr–Mo	½% Mo–V	8% Cr–Mo–Ti	18/12/1 (Cr–Ni–Nb)
3000 h	4·4	5·6	8·7	10·7
10,000 h	3·2	3·9	7·1	8·8

This emphasizes the useful level of rupture strength possessed by this steel.

A fully ferritic steel of the 8% Cr–Mo–Ti type has a low room-temperature impact value due partly to its inherently coarse grain-size, which cannot be refined by heat-treatment, and partly to the alloying elements added to confer high-temperature strength. As the rupture data show, the ductility at temperatures between 566° C (1050° F) and 649° C (1200° F) is good, probably better than that exhibited by some established creep-resisting materials in their particular range of service. Whilst it has proved possible to carry out quite severe fabrication procedures at room temperature, as evidenced by the cold-drawing trials already mentioned, it is considered more suitable to fabricate this material hot, and this can readily be accomplished by conventional methods. An example of hot bending is given in Fig. 27 for a 2 in. outside dia. × ¼ in. wall tube. A possible alternative to the more usual hot bending methods, and one which would not interfere with the creep strength of the steel in any way, might be to carry out fabrication at some temperature above 200° C (392° F) which, as Fig. 28 indicates, lies above the impact transition temperature of this material.

The 8% Cr–Mo–Ti steel can be welded to itself and other ferritic creep-resisting tube steels by argon-arc welding methods. It has not, however, proved possible to get consistently high bend angles on strips cut from welded tubes, and bent over a former, although the welds themselves were metallurgically sound. Such bend tests had their origin in the examination of mild steel and low-alloy steel welded tubes, and it is open to question whether they are necessarily relevant to this particular steel and its intended application. It is considered that in making any such tests to examine the soundness of welds, this aspect should be borne in mind. By using austenitic weld metal 180° bends can be obtained, if required.

CONCLUSIONS

(1) Experimental work has been carried out on intermediate chromium materials with particular reference to fully ferritic steels. The results obtained led to more extensive tests being made upon an 8% Cr, 3% Mo–Ti steel. This material displayed, at 625° C (1157° F) rupture strength intermediate to that of low-alloy ferritic creep-resisting steels and that of an 18/12/1 Cr–Ni–Nb austenitic steel. Its general level of properties suggests that a steel of this type might be suitable for service temperatures up to 621° C (1150° F) and thus fill the gap at present existing between established ferritic and austenitic materials.

(2) The function of titanium in this steel is to provide solid-solution hardening of the matrix, and, to maintain the optimum hardness from this effect, it is desirable to avoid the precipitation of the Laves phase based on Fe_2Ti in the temperature range 750–1050° C.

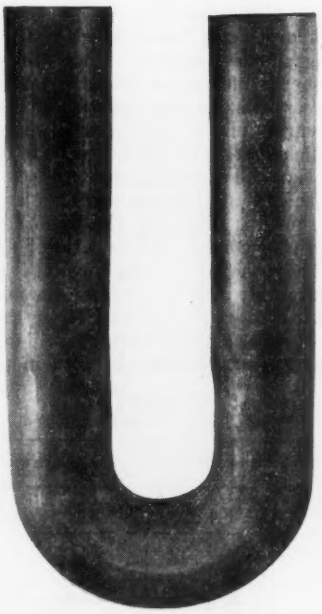


Fig. 27—8% Cr–Mo–Ti tube steel; hot bent tube 2 in. o.d. × ⅛ in. wall

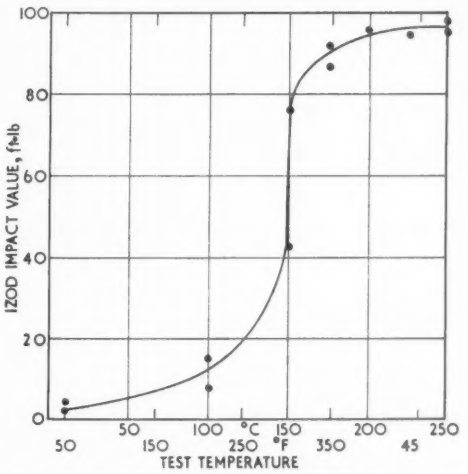


Fig. 28—8% Cr–Mo–Ti steel (cast B6860): Izod-impact/temperature relation

(3) Titanium-bearing constituents other than the Laves phase are also present, but play a minor role. These include a new phase which could be a nitride. X-ray data are given for this constituent (' *Y* phase ') and for Fe_2Ti itself.

(4) Age-hardening due to the precipitation of the carbide $M_{23}C_6$ contributes considerably to the strength of the material at temperatures below about 750° C and is an important factor in the rupture strength of the material as discussed in Part III of the paper.

(5) The occurrence of this carbide in the presence of amounts of titanium in excess of those normally considered adequate for carbide stabilization has been explained. It is clear that titanium is only partially effective in this capacity.

(6) Some general theoretical aspects are indicated, and these include the possible basis for a theory of crystallographic relationships.

(7) The effect of other alloy elements has been considered. These elements—aluminium, tungsten, vanadium, and niobium—do not alter the structure of the material, but aluminium and niobium when present in sufficient amounts reduce the rupture strength of the steel. Niobium tends to replace some of the titanium in the Laves phase and to replace TiC by NbC.

(8) In addition to laboratory tests, fabrication trials have been made upon this steel in tube form. These have suggested that, whilst it is possible to cold-work it, hot-deformation techniques would be more effective.

Acknowledgments

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References

1. F. DOLLIN: *The Chartered Mechanical Engineer*, 1954, Nov., pp. 429–441.
2. H. J. GOLDSCHMIDT: *J. Iron Steel Inst.*, 1948, vol. 160, pp. 345–362.
3. K. W. ANDREWS: *Ibid.*, 1949, vol. 163, p. 384 (discussion of Ref. 2).
4. P. DUMEZ and F. ODELL: *J. Electrochem. Soc.*, 1950, vol. 97, pp. 299–304.
5. F. L. VERSNYDER and H. J. BEATTIE: *Trans. Amer. Soc. Metals*, 1955, vol. 47, pp. 211–226.
6. W. HUME-ROTHERY and G. W. RAYNOR: "The Structure of Metals and Alloys," 3rd ed., p. 244: 1954, London, The Institute of Metals.

The Scale Effect in the Cup Drawing Test

By J. F. Wallace, Ph.D.

SYNOPSIS

The specification of the drawing performance of sheet metals by the cup drawing test is discussed with particular reference to cup diameter, sheet thickness, and blankholder load. Experimental results from cups 1 in., 1⅜ in., 2 in., and 4 in. dia. drawing from sheet thicknesses of 0·012 in., 0·018 in., 0·024 in., 0·036 in., and 0·048 in., show a decrease in limiting drawing ratio with increase of punch diameter and decrease of sheet thickness. Similar limiting drawing ratios for different thicknesses are obtained with the tool geometry in proportion to thickness.

It is suggested that a ¾-in. dia. cup should be used for tests on sheet 0·012–0·016 in. thick and a 2-in. dia. cup for 0·030–0·040 in. thick, although with non-geometric tools similar performance to the smaller cup on thin materials can be obtained from the 2-in. cup.

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IT IS APPARENT from the considerable international attention which is now being given to devising a standard test for the specification of drawing performance of sheet metals that the established tests, and many others which have been suggested, are not satisfactory. The tensile, tear, and Erichsen tests have had limited support and application but emphasis is now being given to the development of a cup drawing test, the parameter of sheet performance being the maximum ratio of cup to blank diameter at which an unfractured cup is drawn.

The majority of pressings are formed by varying degrees of drawing and stretch forming. The flat-based cup, Fig. 1*a*, is a simple drawing operation and thus will only assess drawability. On the other hand the hemispherical based cup, Fig. 1*b*, which has been suggested as a test criterion incorporating an element of stretch forming, is only one simple combination of the two components under special conditions. Consequently, except in special cases, correlation of the performance of sheet between a single secondary test and in the press shop cannot be reasonably expected. Some materials may be more suitable for stretch forming than for drawing and two separate tests of the properties, a flat-based cup drawing test and a stretch forming test, Fig. 1*c*, may resolve some of the present anomalies in the rating of drawing steels. Stretch forming is not considered in this paper.

Obviously, for comparable assessments of drawability from diverse operators and machines, the test conditions should be precisely and practically specified.

Based on paper MW/EA/7/56 of the Cupping Press Sub-Committee of the British Iron and Steel Research Association, received 5th March, 1956.

The views expressed are the author's and are not necessarily endorsed by the Committee as a body.

Dr. Wallace is at the University of Sheffield.

Table I
SIZE-EFFECT ON RANKING

Cup Dia.	1⅜ in.		2 in.		4 in.	
Sheet Reference	L.D.R.	P.R.	L.D.R.	P.R.	L.D.R.	P.R.
A	2·22	1·0	2·17	1·0	2·15	1·0
B	2·27	1·02	2·22	1·02	2·17	1·01
C	2·35	1·06	2·30	1·06	2·24	1·04
D	2·22	1·00	2·17	1·0	2·15	1·0

L.D.R. = Limiting drawing ratio

P.R. = Performance ratio $= \frac{(\text{L.D.R.})}{(\text{L.D.R.})_A}$

Swift, Svahn, Siebel,[1–4] and many other workers have examined some of the variables but the effect of cup diameter and the accommodation of a range of sheet thicknesses are still two of the more controversial factors. From consideration of their particular interests various research groups, equipment and sheet manufacturers, and users, have proposed cup diameters from ½ in. to 4 in. The smaller diameters reduce equipment cost as the press can be hand-operated, and users of thin narrow strip require that the limiting blank diameter is less than the sheet width; but larger cup diameters should be more discriminating and less subject to operator error. For different sheet thicknesses one suggested design of cupping press utilizes a single punch and die, the radial clearance varying from 5% to 500%, while in others a range of thicknesses is covered by each of three or four sets of tools of the same diameter.

Swift's theory of thinning during plastic bending under tension has suggested the hypothesis that for similar drawing conditions the ratio of die radius to sheet thickness should be constant, but it is clear that this will not apply when the cup radius is comparable with sheet thickness; Svahn[2] has shown that with one thickness of sheet and fixed profile radii on punch and die the drawing ratio decreases with increase of cup

Table II
BLANK INCREMENT

1 in. punch 0·036 in. sheet			2 in. punch 0·036 in. sheet		
Blank dia., in.	Draw	Fail	Blank dia., in.	Draw	Fail
2·350	0	10	4·650	0	10
2·345	2	8	4·625	6	4
2·335	5	5	4·600	10	0
2·33	9	1			
2·325	10	0			

diameter. But while the combined effect of profile radii and cup diameter are difficult to analyse quantitatively, similar drawing conditions might be anticipated if the complete scale of the cup and the radial clearance were proportional to sheet thickness.

In the present investigation, the effects of punch dia. and sheet thickness are examined with punches 1 in., $1\frac{3}{8}$ in., 2 in., and 4 in. dia. and tool profiles proportional to nominal sheet thicknesses of 0·012 in., 0·018 in., 0·024 in., 0·036 in., and 0·048 in. These combinations give complete geometric similarity with the 4-in. punch, 0·048-in. sheet; 2-in. punch, 0·024-in. sheet; and 1-in. punch, 0·023-in. sheet. Punch nose and die entry profile radii of 6 and 10 times the sheet thickness respectively and a radial clearance of 30% of the thickness have been adopted after consideration of the experimental results of Chung and Swift.

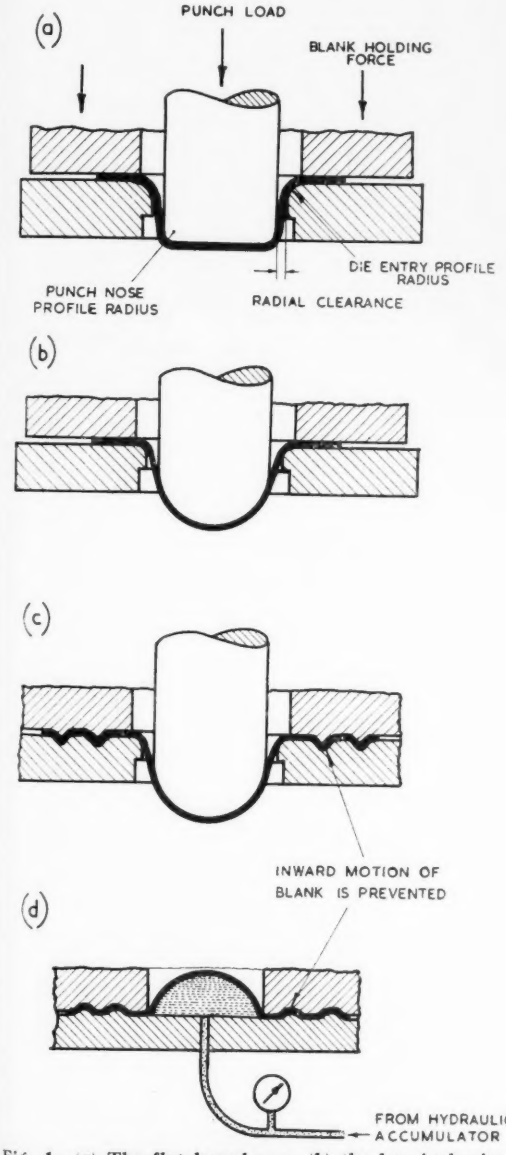

Fig. 1—(*a*) The flat-based cup; (*b*) the hemispherical-based cup; (*c*) stretch forming by hemispherical punch; (*d*) stretch forming by the bulge test

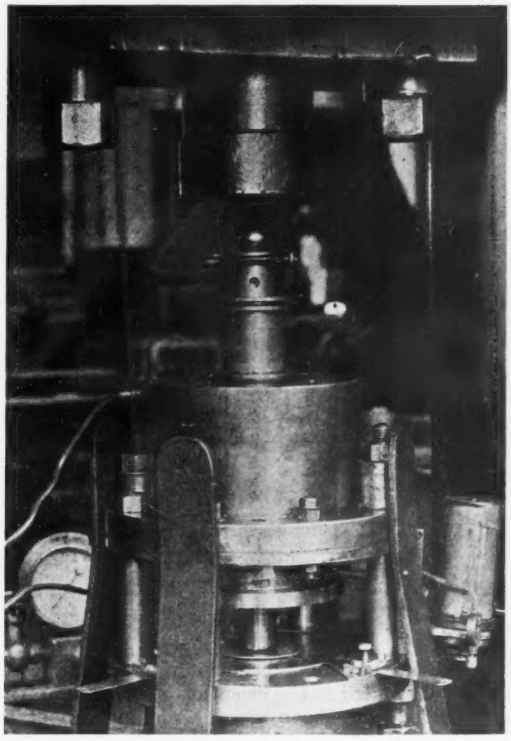

Fig. 2—Sub-press assembled in 100-ton hydraulic press

CONDITIONS IN DRAWING EXPERIMENTS

The five thicknesses of cold-reduced, full-finished, extra deep-drawing quality stabilized steel sheet were especially prepared from the same stock. Cups 1 in., $1\frac{3}{8}$ in., and 2 in. dia. have been drawn in a hydraulic pressure blankholding sub-press (Fig. 2) operated in a constant speed hydraulic press, and 4 in. dia. in the experimental crankpress with air cushion blankholding, drawing across the mid-stroke at a similar average speed to the hydraulic press (3 in./s). All the tools of 'die hard' steel were finish-ground and polished by means of a special grinding attachment to a regular profile and a maximum surface roughness (by Talysurf) of 4 μ. The lubricant, graphite and tallow, has been applied by hand.

RESULTS AND DISCUSSION

An effect of the blankholding load on the limiting drawing ratio for 2-in. cups is shown in Fig. 3. With blank thicknesses less than 0·048 in., there is an optimum blankholder load for the maximum limiting drawing ratio. The decrease in limiting drawing ratio at higher blankholder loads could be due to the increase in the blankholder friction component of the drawing stress, which will become more apparent with the thinner blanks. At less than the optimum blank-

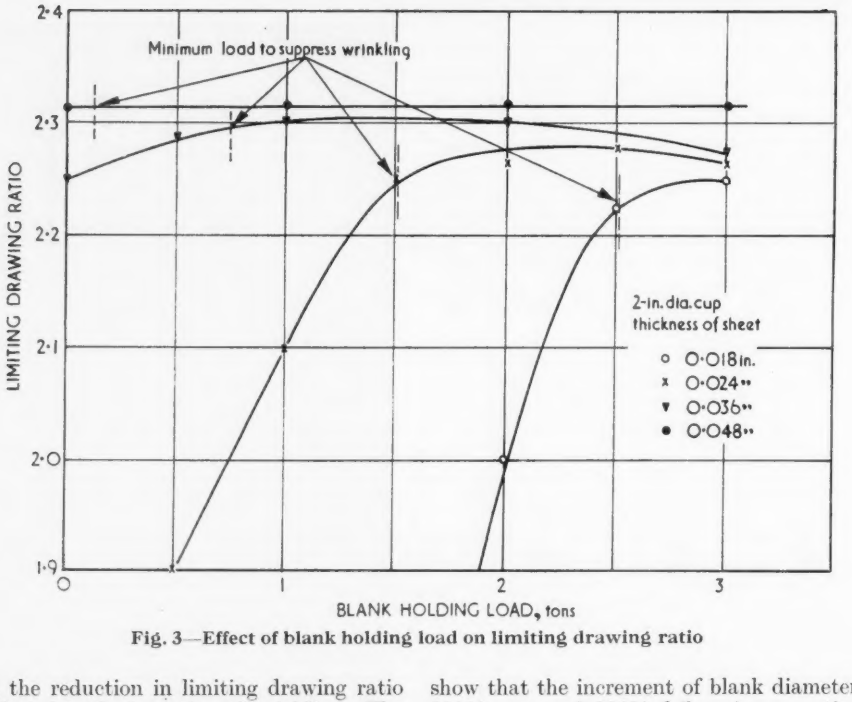

Fig. 3—Effect of blank holding load on limiting drawing ratio

holder load, the reduction in limiting drawing ratio may be attributed to the inception of wrinkling. The blankholder load above which wrinkling cannot be visually detected in the rim of a blank of initially twice the cup diameter when drawn to one and a half times the cup diameter increases rapidly with decrease in blank thickness (Fig. 4) and is about two-thirds of the optimum blankholder load. In the scale effect investigation, the optimum load for each blank diameter and thickness has been adopted in an attempt to maintain comparable blankholding conditions.

Svahn[2] has shown that the ranking of 5 sheets (3 steel, 1 brass, and 1 aluminium) by the cup drawing test is not altered by cup diameter. Table I, which gives similar results from the drawing of four only slightly differing qualities of steel sheet suggests that, with any cup diameter, drawability could be specified relative to a standard material. However, in most cases, this method of test would be inconvenient and such a standard may be difficult to maintain over a period.

A limiting drawing ratio which could be regarded as a unique value of drawability independently of sheet thickness would simplify the classification and manufacture of drawing sheet, especially for use in the annealed condition. Consistency tests (Table II) show that the increment of blank diameters between 100% pass and 100% failure is proportional to cup diameter and with the particular steel sheet used is 0·025 increment of blank diameter. Acceptable variance on sheet would normally not be expected to be less than ± half of this increment, while in many cases ± one increment would be more usual. In consequence, it seems not unreasonable that for com-

Table III*a*

GEOMETRIC SCALE EFFECT

Cup dia., in.	Sheet thickness, in.	L.D.R.
4	0·048	2·25
2	0·024	2·275
1 3/8	0·016	2·24
1	0·012	2·225

Scale: Cup diameter to sheet thickness = 1 0·012
N.B.—1⅜ in., 0·016 in. figure is from interpolation

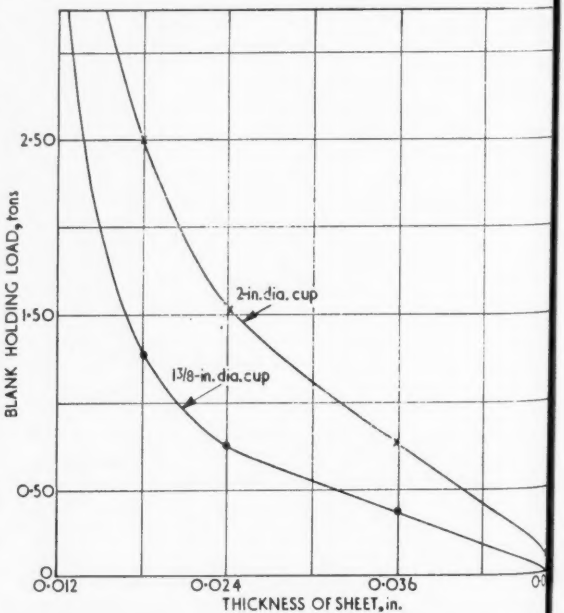

Fig. 4—Effect of sheet thickness on blank holding load to prevent wrinkling

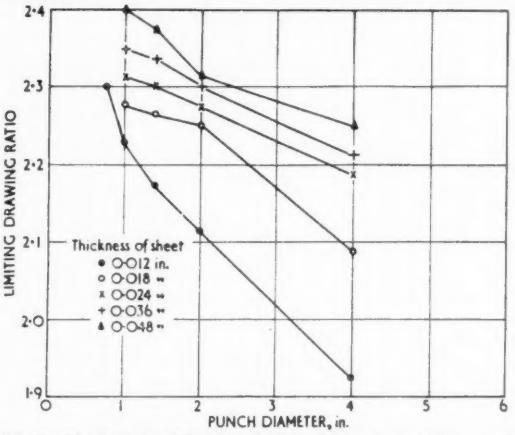

Fig. 5—Variation of limiting drawing ratio with punch diameter (profile radii proportional to sheet thickness)

mercial comparison of different gauges a tolerance of ± one increment could be allowed. Tables III*a* and *b* show that this is attained within the range of sheet thicknesses 0·012–0·048 in., if the cup diameter, die and punch profile radii, and the radial clearance, are in proportion to the blank thickness. The tooling required for the exact application of this principle to each standard gauge in the range 0·012–0·048 in. would be prohibitive for commercial test equipment, but this number can be reduced by taking into account the available tolerance.

With constant blank thickness, the limiting drawing ratio decreases with increase of cup diameter (Fig. 5). The complementary Fig. 6 shows that the rate of increase of limiting drawing ratio with sheet thickness is lower with the thinner gauges when drawing the smaller diameter cups. The sheet thicknesses used, 0·012–0·048 in., can be divided into three ranges, 0·012–0·018 in., 0·016–0·024 in., and 0·024–0·048 in., in each of which one punch dia. 1 in., 2 in., and 3 in., respectively should give the limiting drawing ratio within the tolerance (± 0·025 in.) of the value with

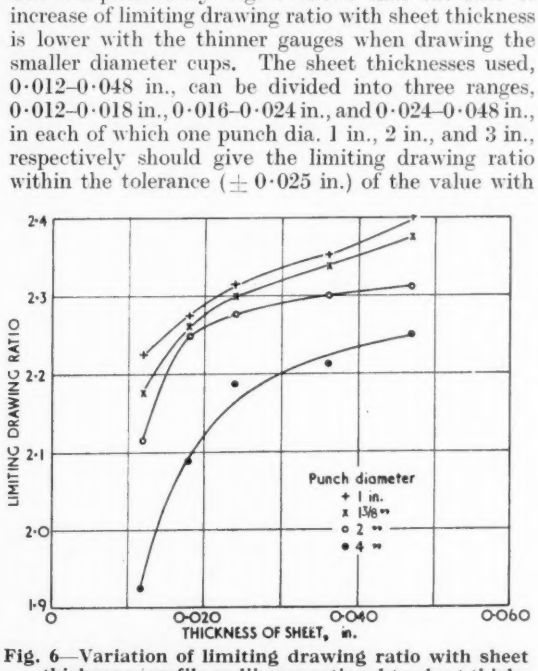

Fig. 6—Variation of limiting drawing ratio with sheet thickness (profile radii proportional to sheet thickness)

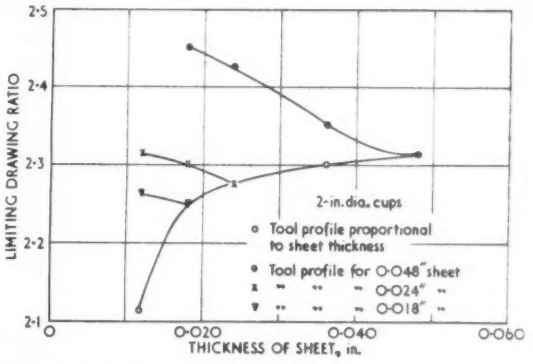
LIMITING DRAWING RATIO
THICKNESS OF SHEET, in.
2-in. dia. cups
○ Tool profile proportional to sheet thickness
● Tool profile for 0·048" sheet
x " " " 0·024" "
▼ " " " 0·018" "

Fig. 7—Using one tool set to draw a range of sheet thicknesses

punch dia. to sheet thickness scale of 1/0·012 in.; the 3-in. dia. cup values are estimated. With a scale of 1/0·018 in. the ranges are: 2-in. punch, 0·048–0·024 in.; 1-in. cup, 0·024–0·016 in.; and ¾-in. cup, 0·016–0·012 in. (estimate); the 2-in. cup range contains the usual thicknesses of automobile body panel steels.

Furthermore, when the tolerance is taken into account, the number of tool sets (punch and die) of each diameter can be considerably reduced from the number required for every standard gauge in each range. With a fixed tool profile, until the inception of wrinkling in the die entry, there is an increase in limiting drawing ratio with decrease in blank thickness (Fig. 7). To accommodate the 0·024–0·048 in. range of thicknesses with the 2-in. cup within ± 0·025 of a scale value of limiting drawing ratio would seem to require two tool sets, but one set only may cover the suggested ranges for the smaller cups.

So far the argument has been for the use of a smaller cup for drawing tests on thin sheet, but Fig. 6 also shows that it should be possible with three or four tool sets of 2-in. dia. to obtain a scale value of limiting drawing ratios over the full ranges of sheet thicknesses, 0·012–0·048 in. Thus it seems that two sizes of cup drawing test, say ¾ in. dia. for narrow strip and 2 in. dia. for sheets, could be designed and standardized. With tool profile proportional to cup diameter, the drawability assessment of 0·012–0·016 in. sheet with ¾-in. dia. cup should be directly comparable to 0·030–0·040 in. with the 2-in. dia. cup; but a small number of special profile tools could be provided at each diameter to give reasonably comparable limiting ratios over the full range.

With the exception of Table I, the experimental

Table III*b*

GEOMETRIC SCALE EFFECT

Cup dia., in.	Sheet thickness, in.	L.D.R.
2¾	0·048	2·28
2	0·036	2·3
1⅜	0·024	2·3
1	0·018	2·27
¾	0·012	2·3

Scale: Cup diameter to sheet thickness = 1/0·018
N.B.—2¾ in., 0·048 in. figure is from interpolation

results discussed have been obtained on only one type of steel. Nevertheless, as the applied variables were geometric, it appears not unreasonable to give a tentative general application to the conclusions.

Acknowledgments

The work has been performed at Sheffield University under the guidance of Professor H. W. Swift, D.Sc., M.A., in co-operation with a similar investigation on small cups by V. Chapman, B.Sc., at Leeds College of Technology. The author wishes to thank the suppliers of tool steel and strip and all concerned for advice and assistance.

References

1. J. Willis: " Deep Drawing," 1954, London, Butterworths.
2. O. Svahn: *J. Iron Steel Inst.*, 1954, vol. 177, pp. 129–142.
3. E. Siebel: Quoted in H. Beisswänger: *Metall*, 1952, vol. 6, p. 744.
4. H. Swift: *Engineering*, 1948, vol. 166, pp. 333–335; 357–359.
5. S. Y. Chung and H. W. Swift: *Proc. Inst. Mech. Eng.*, 1951, vol. 165, p. 199.
6. E. C. Seed and H. W. Swift: *Ibid.*, 1950, vol. 163, p. 125.

The Tempering of Plain Carbon Steels

By E. D. Hyam, M.A., Ph.D., and J. Nutting, M.A., B.Sc., Ph.D.

SYNOPSIS

Electron metallographic techniques have been used to follow the changes in microstructure resulting from tempering four plain carbon steels in the temperature range 500–700° C. The carbide particle size distributions have been obtained and from these results it has been possible to calculate the changes of individual particle diameters during the progress of tempering.

The progress of tempering has also been followed by taking hardness measurements, and from these it has been possible to calculate the activation energy of the softening process. The values obtained were $\simeq$ 60 kcal/g-mol and it is concluded that softening is controlled by a mechanism involving the self-diffusion of iron.

The various relationships which have been proposed between parameters of the microstructure and hardness are discussed and compared with the present results. It is concluded that none of the previously established relationships accounts satisfactorily for the changes in steels during tempering.

A new mechanism is proposed for tempering. It is suggested that the hardness of tempered steels depends upon the ferrite grain size—the larger the grains, the softer the steel. The growth of the ferrite grains is limited by the carbide particles which are present at the ferrite grain boundaries; therefore, during tempering, as the carbide particles grow, so the ferrite grains can grow and the steel becomes softer.

This mechanism is supported by the fact that a linear relationship has been observed between the hardness and the reciprocal of the square root of the ferrite grain diameter. 1239

DURING THE TEMPERING of quenched carbon steels, changes in microstructure are produced over a wide range, resulting in corresponding changes in mechanical properties. At present little is known about either the dependence of the mechanical properties on the microstructure, or the detailed mechanisms of the microstructural change during the tempering process, especially during its last stage.

Surveys[1,2,3,4] of the published results of investigations show that a wide variety of techniques has been used to study the process of tempering. The literature is voluminous and, therefore, reference will be restricted here to the more important investigations of the constitutional changes in structure and physical properties produced during tempering, and of the relation between mechanical properties and microstructure.

Changes in Structure

Quench-hardened carbon steels have the structure of tetragonal martensite; they may also contain face-centred cubic austenite in varying amounts. The changes in physical properties during tempering result from the combined effects of the decomposition of these two solid solutions and are observed to occur in three stages. It is now well recognized that these correspond to:

(i) Precipitation of close-packed hexagonal ϵ-carbide
(ii) Decomposition of retained austenite
(iii) Formation from the ϵ-carbide of thin platelets of orthorhombic cementite, Fe_3C. From these, a microstructure of spheroidal cementite develops, which then coarsens with further tempering.

The underlying reactions here are time-dependent and occur either isothermally or on heating. Moreover, the three stages do not occur entirely consecutively; the third stage overlaps the second and both may partially overlap the first.

These descriptions of the structural changes which occur during the three stages of tempering are supported by the electron metallographic investigations of Trotter and McLean,[5] and Lement *et al.*[6,7]

Although no further constitutional changes occur as tempering progresses, the microstructure and the mechanical properties continue to alter. This is due to the development, from the first-formed platelets, of non-coherent spheroids of cementite which gradually grow in size and decrease in number. This change, as has long been recognized,[1,8] can only occur by the solution of the smaller particles, diffusion of carbon through the ferrite, and simultaneous growth of the larger particles. It is similar in character to over-

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Dr. Hyam, who is a Senior Scientific Officer with the United Kingdom Atomic Energy Authority (Industrial Group), was formerly at the Department of Metallurgy, Cambridge University. Dr. Nutting is Lecturer in Metallurgy at Cambridge University.

ageing in age-hardening systems. This part of the tempering process might well be regarded, therefore, as a separate stage of tempering—the fourth stage.

Changes in Mechanical Properties

The changes in the mechanical properties of tempered carbon steels associated with the microstructural changes in the over-ageing stage are well known. For example, progressive tempering of a steel results in a decrease in hardness, yield stress, ultimate tensile stress, and creep properties, and an increase in ductility and impact strength. Several investigators[8,9,10,11] have noted that hardness decreases linearly with the log of the tempering time on isothermal tempering but, unfortunately, changes in mechanical properties are generally given in the literature as a function of the tempering temperature for some arbitrary time of tempering; even the isothermal hardness data available do not appear to include systematically the effect of carbon content. The investigations of Hollomon and Jaffe[11] were the first to provide comprehensive data on the changes of hardness with tempering time for a wide range of temperatures and for different carbon steels. From their results, they were able to devise an empirical relationship between the time–temperature conditions of tempering and the hardness.

Relation between Mechanical Properties and Microstructure

The characterization of these changes in mechanical properties in terms of the accompanying changes in the microstructures of tempered carbon steels forms a particular aspect of the more general problem of the relation between microstructure and mechanical properties in two-phase alloys. The problem is complex and, despite its importance, has hitherto been the subject of few investigations.

The first quantitative study was that of Gensamer and co-workers,[12] who found that the tensile strength, hardness, and flow strength of several steels decreased linearly with the log of the mean free-ferrite path and that the same linear relationship held for pearlitic, spheroidized, and tempered structures, irrespective of the amount of the carbide phase. The values of the mean free-ferrite path ranged from $0{\cdot}15\mu$ to 55μ.

Recent work by Roberts, Carruthers, and Averbach[13] shows that the elastic limit and yield stress of a number of irons and iron–carbon alloys vary with microstructure in the same way, although anomalous values are obtained in the case of high-purity iron.

On the other hand, Shaw *et al.*,[14] in a recent work on various over-aged Al–Cu alloys, find that their values of the log of the mean free path correlate better with the log of the flow stress (the true stress for $0{\cdot}2$ strain). Again the amount of the dispersed $CuAl_2$ phase or the shape of the particles appears to have no effect on this relationship.

Shaw *et al.*[14] also calculated from their data the volume mean free path, i.e. the mean free path in a volume of matrix, as distinct from that in a plane through the matrix, and found the same correlation with the flow stress as with the planar mean free path.

Gensamer[15] has also determined the work-hardening index n for a number of different steels showing a variety of structures, and has found that, within a broad scatter band, there was a continuous variation of n with flow strength. However, Shaw *et al.*[14] pointed out that the data could also indicate that this is true only within each type of structure.

Two other quantitative investigations have been carried out, both on tempered steels. Wood,[16] using X-ray diffraction methods, deduced that the hardness decreased linearly with the reciprocal of the square of the particle diameter. Shimura and Esser[17] tempered several hardened carbon steels, ranging in composition from $0{\cdot}65\%$ C to $1{\cdot}75\%$ C, at 700–720° C for varying times up to 48 h, and then correlated the resulting hardness with the number of carbide particles observed optically in unit area of section surface. They found that for any one steel the data lay on a smooth curve, but that variation in carbon content produced a family of curves. For the same number of particles in the microstructure, a higher carbon content resulted in an increase in hardness.

Together with these experimental investigations, a number of theoretical studies have been carried out. These have been based largely on the dislocation concept of plastic flow and have required various simplifying assumptions to be made about the two-phase structures considered, e.g. that the particles are spherical, randomly dispersed in the matrix, and uniform in size, and do not deform with the matrix. It should be noted that, while the first two approximations may hold for the case of tempered steels, the third does not and the validity of the fourth is doubtful.

Gensamer[12] had interpreted his results in terms of a dislocation model which must now be regarded as only approximate. Early work by Bragg[18] also led to the expectation that some dimension of the structure which is characteristic of it, in the same way that Gensamer's mean free-ferrite path is a characteristic dimension, should be a function of the plastic properties of the aggregate. The relation developed was:

$$\gamma_{\text{Lim}} = \frac{\text{constant}}{\delta} \qquad \ldots\ldots(1)$$

where γ_{Lim} is the shear strain at the elastic limit, the value of the constant is of the order of unity, and δ, the value of the characteristic dimension, is the size of the crystal element whose strain is relieved by slip of a single inter-atomic distance.

The theory of precipitation hardening put forward by Mott and Nabarro[19] has been extended by Orowan[20] to include the case of coarse over-aged structures. By considering a dislocation line, held up by a row of particles of spacing Λ, to bulge between them under an applied stress until loops of radius $\Lambda/2$ are formed at the yield stress y, he obtained the relation:

$$y = \frac{2\,G\,d}{\Lambda} \qquad \ldots\ldots(2)$$

where G is the shear modulus and d is the atomic spacing.

Allen[21] noted that, according to Bragg, Mott and Nabarro, and Orowan, the strength of a steel should be proportional to the reciprocal of the characteristic dimension, but to its log according to Gensamer. He suggested that measurements made on electron micrographs of tempered steels might serve to establish the respective merits of the two relationships. Shaw *et al.*[14] applied the theories of both Gensamer and Orowan to their own data but found neither wholly satisfactory.

Recently, Fisher, Hart, and Pry[22] have proposed a rather different hardening mechanism, based however on a similar dislocation model. Successions of dislocation loops from Frank–Read sources pass between the particles intersecting the slip-plane and leave these particles surrounded by many small closed loops. These latter set up back-stresses which raise the effective critical stresses of all Frank–Read sources in the plane. The hardening increment identified with these back-stresses is then given by:

$$\frac{1}{\tau_c} = \frac{r}{N} = \frac{3f^{3/2}}{\tau_h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where τ_c is the value of the critical stress for the yielding of the particles or surrounding matrix, r is the radius of the circular sections of the particles in the slip-plane, N is the number of dislocation loops supported by each particle, f is the volume fraction of the precipitate, and τ_h is the hardening increment, the difference in stress for equal strain of the two-phase structure and the single-phase matrix.

These authors applied this relationship to the data of Shaw *et al.*,[14] plotting $f^{3/2}/\tau_h$ against r. The resultant points lay broadly scattered about a straight line, in the range 0·2–2·7μ, and showed that τ_c decreased with increasing values of r, as would be expected.

An analysis not based on dislocation theory was put forward by Unckel,[23,24] who considered the shearing forces acting in successive layers below the plane of application of the deforming stresses. He proposed that the force K necessary for the deformation of the aggregate could be related to the mean particle spacing y by the expression:

$$K = Ae^{-By} + C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where C = strength of the matrix and A = the difference between the strengths of the dispersed phase and the matrix.

This formulation has the merit that, at zero spacing, K is equal to the deformation strength of the second phase, i.e. $A + C$, and, at infinite spacing, K is equal to the deformation strength of the matrix, i.e. C. The constant B is dependent on the way in which the shear forces decrease with distance from a particle.

Scope of the Present Investigation

From this review it is clear that there is much to be gained from a detailed examination of the fourth stage of tempering in carbon steels. Moreover, there are several points about the structures produced in this stage of tempering which facilitate such an examination. The cementite particles are approximately spheroidal, they are non-coherent with the ferrite matrix, and not only can their amount be varied by use of a steel of different carbon content, but their degree of dispersion can also be varied over an extremely wide range by suitable adjustment of a simple heat-treatment process.

The present investigation was carried out with the intention both of obtaining the full quantitative data about the microstructural changes in the fourth stage of tempering, which have hitherto been lacking, and of using this information to examine, in the light of the various studies noted above, the relation between mechanical properties and microstructure.

Four plain carbon steels, differing principally in carbon content, were tempered under differing conditions of time and temperature to produce in each a series of different structures. The microstructures were examined by using the electron microscope, in conjunction with the dry-stripped Formvar replica technique. The information obtained from the electron metallographic examination included data on the amount and degree of dispersion of the carbide particles, and on the ferrite grain size of the matrix. The determination of the degree of dispersion requires the measurement of the complete size-frequency distribution of particles observed in an etched plane of section through each specimen; this distribution was transformed to give the true distribution existing in a volume of the steel, in order that the results could be related to the mechanical properties of the aggregate. In conjunction with metallographic examination, the Vickers diamond-pyramid hardness was measured on all specimens, and, on a selected range of specimens, the Meyer work-hardening index was determined.

EXPERIMENTAL METHOD

Materials. Preparation and Heat-treatment of Specimens

The four plain carbon steels used were obtained from the British Iron and Steel Research Association; two were of acid and two of basic O.H. quality. Their compositions are given in Table I.

The specimens for hardness measurements and metallographic examination were austenitized for 1 h at 50° C above the appropriate A_3 temperature, quenched into iced brine, and subsequently refrigerated in liquid air to reduce the amount of any retained austenite to a minimum. Each specimen then received a single tempering treatment followed by quenching in water. The temperatures employed were 500°, 600°, 650°, and 700° C, and the treatments were carried out over the following ranges of time intervals: ½, 1, 2, 5, 10, 20, 50, and 100 h. The Meyer hardness determinations were carried out only on specimens tempered for 1, 10, and 100 h at 500°, 600°, 650°, and 700° C.

Metallographic Examination

The specimens were mechanically polished and lightly etched for about 20 s in ½% Nital. Formvar replicas were dry-stripped from them and examined in the electron microscope. Two electron micrographs were obtained at a magnification of × 2500 from each specimen and then enlarged to a final magnification of × 10,000.

Measurement of Ferrite Grain Size

Estimates of the size of the ferrite grains, where they were visible in these tempered structures, were obtained by taking the average of the long and short axes of about 30 grains chosen at random in each case.

Microstructural Analysis

The sizing of the particles was carried out also on the enlarged prints of the electron micrographs. An area sufficient to contain 500–700 particles was examined, the particles being compared with a set of standard circles printed on a lantern slide. The diameters of the matching circles were in a $\sqrt{2}$ progression of size, each size being given a ϕ-value. The diameter (d_μ) of a particle in μ is related to its ϕ-value

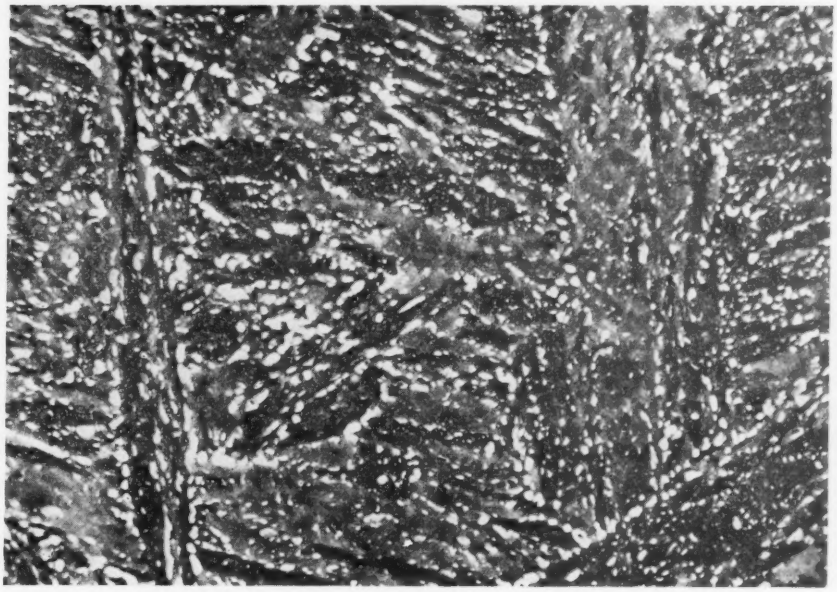


Fig. 1—Electron micrograph of Formvar replicas from 0·3% C steel tempered for ½ h at 500° C × 10,000

(d_ϕ) at a magnification of × 10,000 by the expression:

$$d_\mu = \frac{(\sqrt{2})^d \phi}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Equivalent values of d_ϕ and d_μ at the magnification stated are shown in Table II.

The planar size-frequency distribution having been determined, a mathematical transformation of the observed data was applied in order to obtain the true size-frequency distribution of carbide sphere diameters existing in a given volume of the steel. An account of the method used is given in an Appendix.

From the derived sphere size-frequency distribution of carbide particles in a known volume of matrix, the various parameters characteristic of the distribution were found by simple calculation. These were: the particle diameter, surface, and volume; total particle surface and total particle volume in unit volume of matrix; total number of particles in unit volume of matrix; and the mean spacing between the particles.

The observed circle diameter distribution, gave the number of particles in unit area of section surface.

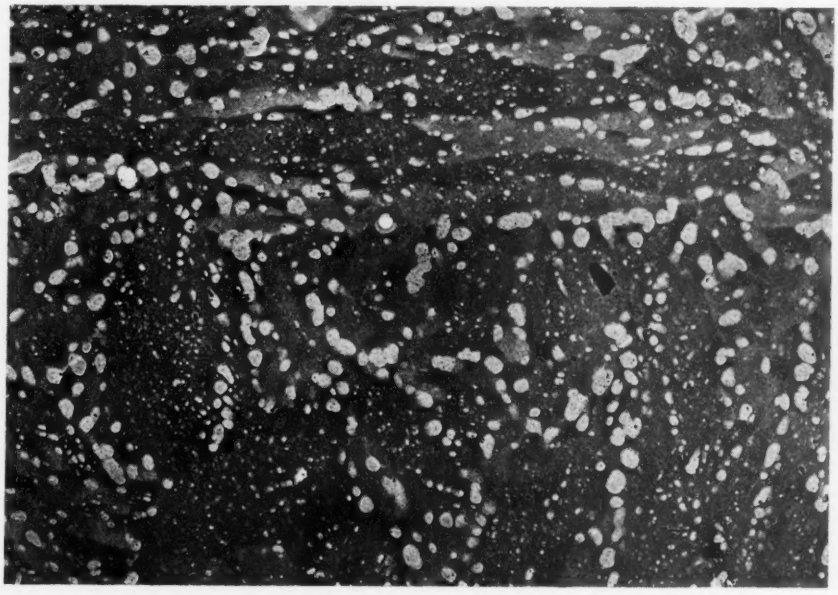


Fig. 2—Electron micrograph of Formvar replicas from 0·3% C steel tempered for 100 h at 500° C × 10,000

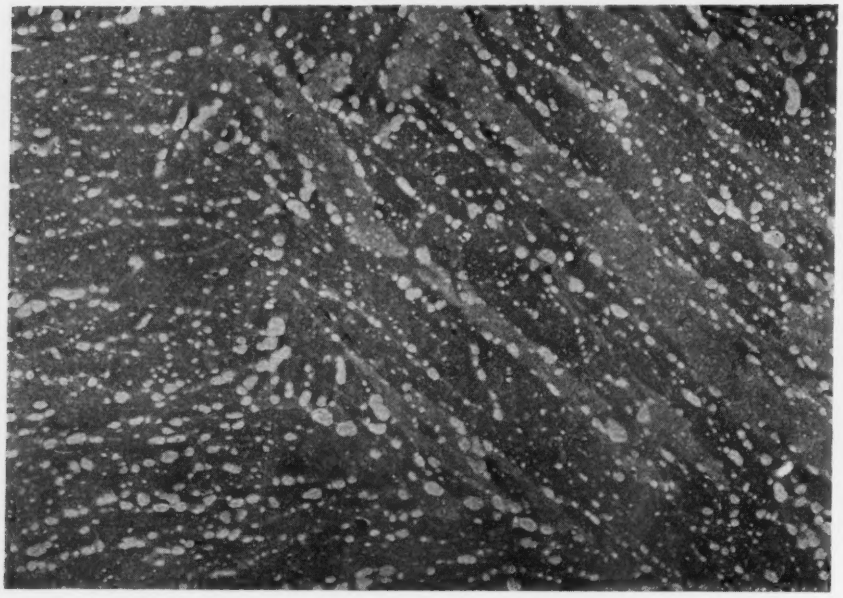


Fig. 3—Electron micrograph of Formvar replicas from 0·3% C steel tempered for ½ h at 600° C × 10,000

Vickers Hardness Measurements

After the specimens had been metallographically examined, Vickers hardness measurements were made, the mean of five values being taken in each case.

Meyer Index Determinations

The indentations were carried out using a 1-mm ball and loads of 10, 12·5, 17·5, 22·5, 30, 40, 63·5, and 100 kg. The value of the Meyer work-hardening index was found graphically from the log–log plot of load against impression diameter.

EXPERIMENTAL RESULTS

General Description of the Microstructures

The tempering treatments employed produced microstructures consisting of approximately spherical particles of iron carbide dispersed in a matrix of ferrite. These microstructures varied both in the degree of dispersion of the carbide phase and in the amount of carbide present.

A selection of the electron microstructures, printed at a magnification of × 10,000, is presented in Figs. 1–6 to illustrate the extent to which the fineness of the

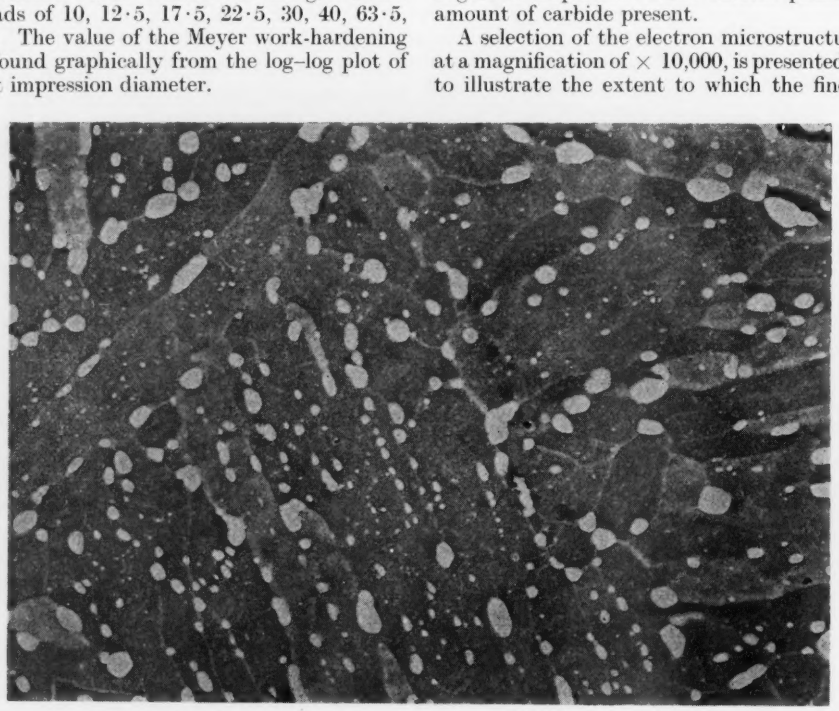


Fig. 4—Electron micrograph of Formvar replicas from 0·3% C steel tempered for 100 h at 600° C × 10,000

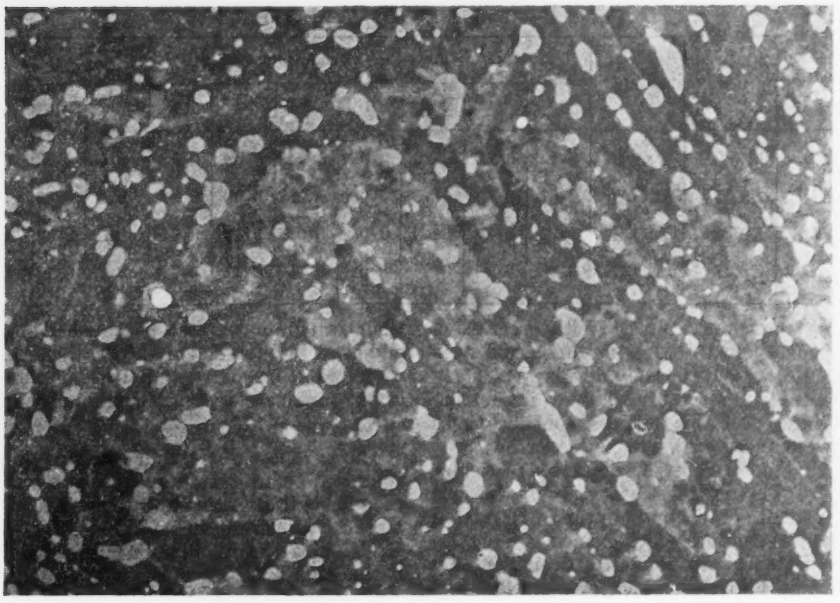


Fig. 5—Electron micrograph of Formvar replicas from 0·3% C steel tempered for ½ h at 700° C × 10,000

carbide dispersion altered in each temperature range for the 0·3% C steel. These electron micrographs show, in somewhat greater detail, the same qualitative changes as those found by Trotter and McLean[5] to occur on tempering a 0·6% C steel at various temperatures up to 700° C.

Two features were frequently observed on the micrographs of some of the finer structures, namely, precipitation of carbides along the pre-existing austenite grain boundaries and the presence of lenticular areas, adjacent to the austenite boundary, in which the carbide particles are of smaller and/or more uniform size than elsewhere; both these features are shown in Fig. 1. It is thought that the lenticular areas represent regions of retained austenite, which decomposes at a slower rate during tempering.

Both the traces of the prior austenite grain boundaries and the lenticular areas frequently associated with them were only observed in those microstructures obtained by tempering for short times

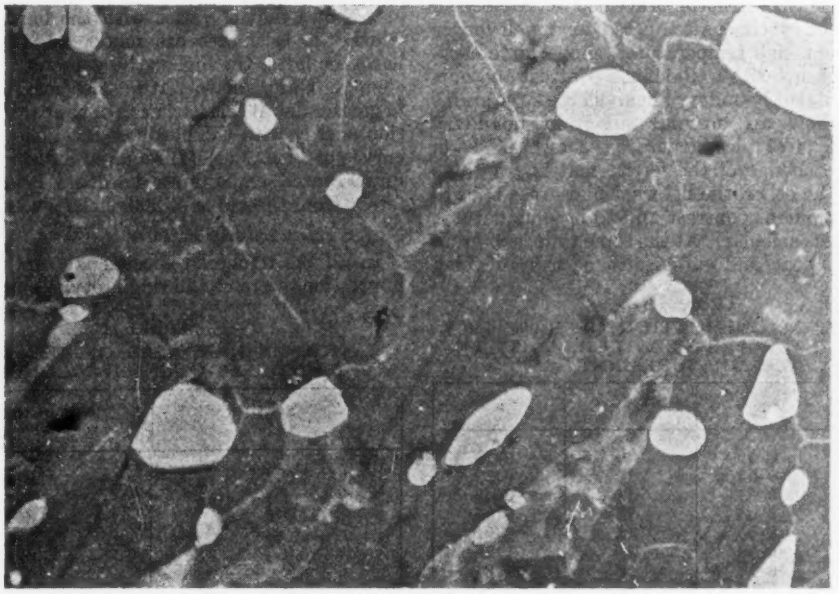


Fig. 6—Electron micrograph of Formvar replicas from 0·3% C steel tempered for 100 h at 700° C × 10,000

Table I—ANALYSES OF THE STEELS

Designation	B.I.S.R.A. Reference	Specification (*BS970*)	Quality	Chemical Analysis, %										Austenitizing temperature, °C
				C	Si	Mn	S	P	Ni	Cr	Mo	Cu	Al	
0·1% C	*BBL*	*En 32B*	B.O.H.	0·125	0·22	0·70	0·057	0·042	0·09	0·06	>0·05	0·23	0·02	950
0·3% C	*CBD*	*En 8*	B.O.H.	0·34	0·30	0·75	0·035	0·037	0·08	0·07	>0·05	0·11	0·02	865
0·7% C	*CJD*	*En 42*	A.O.H.	0·79	0·19	0·65	0·038	0·036	0·10	0·04	>0·05	0·11	0·015	775
0·9% C	*DAD*	*En 44*	A.O.H.	0·985	0·23	0·64	0·05	0·032	0·12	0·07	>0·05	0·12	>0·005	850

and/or at the lower temperatures. With progressive coarsening of the microstructures on further tempering, both these features ultimately disappear.

The ferrite matrix structure showed interesting features. In those specimens tempered for short times and/or at low temperatures, it consists of adjacent light and dark (i.e. in relief or depressed) acicular patches (Fig. 3). These patches occur as sub-divisions of the prior austenite grains and appear to be related to the martensitic structure which existed before tempering. The patches are rendered prominent by strings of carbide particles, which are smaller than those at the austenite grain boundaries but larger than those within the patches, along the boundaries between the light and dark areas.

There is evidence, especially from work by Entwisle and Hirsch,[25] that these fairly large areas of light and dark contrast represent regions, numbering between five and eight per austenite grain, which are related to the prior martensite structure, and each of which contains ferrite grains whose orientations do not differ greatly amongst themselves. However, the value of 60 μ, given by these authors for the mean diameter of any one aggregate of similarly orientated ferrite grains, is much larger than the size of the areas observed here.

The ferrite matrix structure, revealed in the electron micrographs of specimens tempered for much longer times and/or at high temperatures, shows large equi-axed ferrite grains with well-defined contrast and outlined by prominent boundary films. These large grains frequently show an internal sub-grain boundary structure; a typical microstructure is shown in Fig. 6.

During the change of the ferrite matrix from one structure to the other, the light acicular areas tend to lose their prominent contrast and to become patchy, diffuse, and less acicular. At the same time, sub-grain boundaries appear and sub-grains, as they develop their own grain contrast, become less and less acicular and grow into large equi-axed grains. There appears, therefore, to be observational evidence of simultaneous grain growth and recrystallization of the ferrite grains.

Table II

SIZES AT MAGNIFICATION OF 10,000 OF STANDARD CIRCLES USED FOR PARTICLE SIZE MEASUREMENT

ϕ	μ	ϕ	μ
1	0·01	9	0·23
2	0·02	10	0·32
3	0·03	11	0·45
4	0·04	12	0·64
5	0·06	13	0·91
6	0·08	14	1·28
7	0·11	15	1·81
8	0·16	16	2·56

Vickers Hardness Measurements

The hardness of the four steels in the as-quenched condition before tempering is shown in Table III and the effects of duration and temperature of tempering on these values are shown in Figs. 7 (*a*)-(*d*). The four steels show the familiar linear relationship between hardness and the log of the tempering time.

In order to obtain values for the activation energy of the tempering process, a convenient hardness value was chosen. The log of the times t required to reach this hardness at each of the four tempering temperatures by the four carbon steels was plotted against the reciprocal of the absolute tempering temperature, T, the values being read directly from the curves of Figs. 7 (*a*)–(*d*), which were extrapolated where necessary. Table IV shows the activation energies Q which were obtained from the slopes of the straight lines through the plotted points.

For a constant hardness level of 200 Vickers, the value of the activation energy diminishes with increase in the carbon content of the steel. Table IV also shows that Q varies with the hardness level at which the estimates are made, i.e. the higher the hardness level, the higher the value of the activation energy. Unfortunately, it was not possible to examine in greater detail this variation of the calculated activation energy with the hardness level chosen, since the curves of Figs. 7 (*a*)–(*d*) required extrapolation by an unwarranted amount for hardness levels much different from the value of 200 Vickers used here.

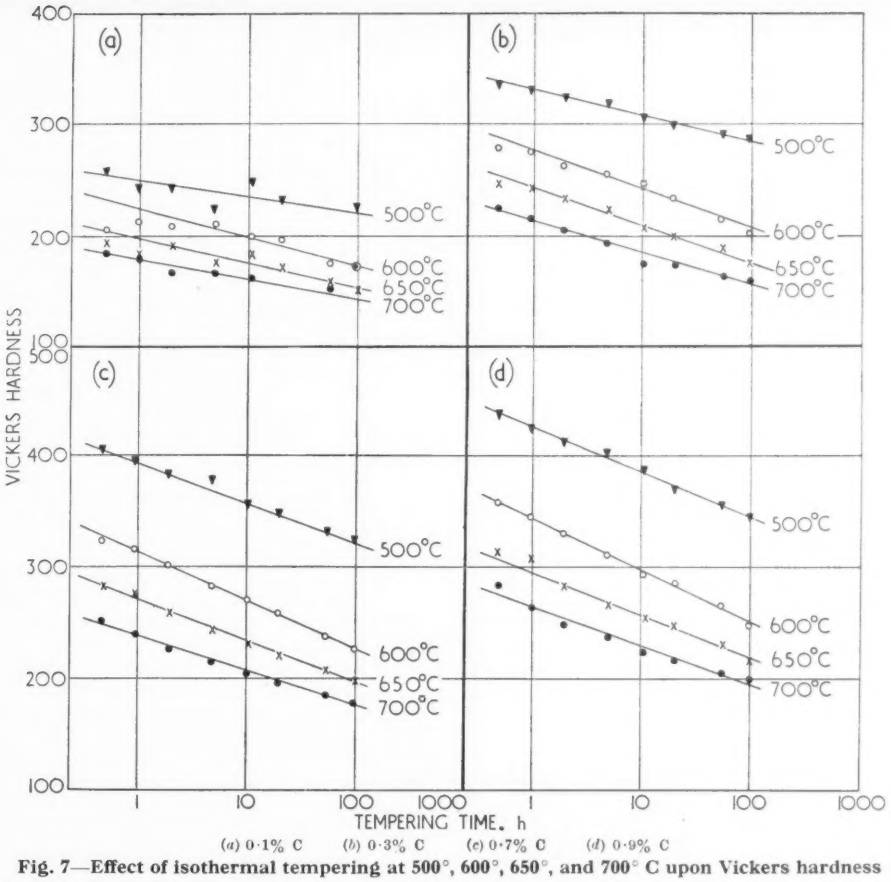
Meyer Index Determinations

In all the tempered specimens examined, the ball impressions were of the ridging type and values for n

Table III

VICKERS HARDNESS OF THE STEELS IN THE AS-QUENCHED CONDITION

Steel C, %	Vickers Hardness as Quenched
0·1	388
0·3	659
0·7	898
0·9	922



(*a*) 0·1% C (*b*) 0·3% C (*c*) 0·7% C (*d*) 0·9% C

Fig. 7—Effect of isothermal tempering at 500°, 600°, 650°, and 700° C upon Vickers hardness

between 2·15 and 2·30 were found. There was a slight increase in n with time and temperature of tempering and with carbon content, but it is noteworthy that the work-hardening properties of the ferrite matrix should be so little dependent upon the distribution of the carbide particles, especially in view of the wide range of structures examined. The value of n for annealed Armco iron was found to be 2·24. Thus the tempered specimens seem to behave as fully annealed material, whereas the opposite deduction would have been made from the ridging effect shown by ball impressions.

Ferrite Grain-size Measurements

The ferrite grains become larger with increase in tempering time and tempering temperature, but in most cases ferrite grain growth was seen to be relatively slow after times in excess of 25 h. The results for 0·7% C steel are shown in Fig. 8. As in the case of hardness, the effect of temperature was very marked.

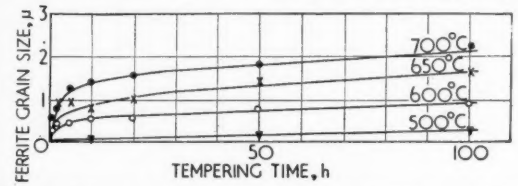


Fig. 8—Ferrite grain growth with isothermal tempering at 500°, 600°, 650°, and 700° C of 0·7% C steel

The minimum grain diameter which could be detected was approximately 0·05 μ and the maximum grain size found was about 6·0 μ, but some doubt exists as to the absolute accuracy of the measurements. It was difficult, in the case of specimens in the intermediate stages of tempering, to decide whether the grain size to be measured was to be the 'contrast grain size' or the 'sub-grain size', and whether individual grains were sub-grains or not. The problem is apparent in the microstructure shown in Fig. 3.

Table IV

ACTIVATION ENERGIES OF SOFTENING FOR THE STEELS AFTER TEMPERING TO THE SAME AND TO DIFFERENT HARDNESS LEVELS

Steel C, %	Hardness	Activation Energy, kcal/g-mol	Hardness	Activation Energy, kcal/g-mol
0·1	200	76·3	190	76·0
0·3	200	67·5	230	80·6
0·7	200	51·7	250	70·5
0·9	200	47·9	270	67·5

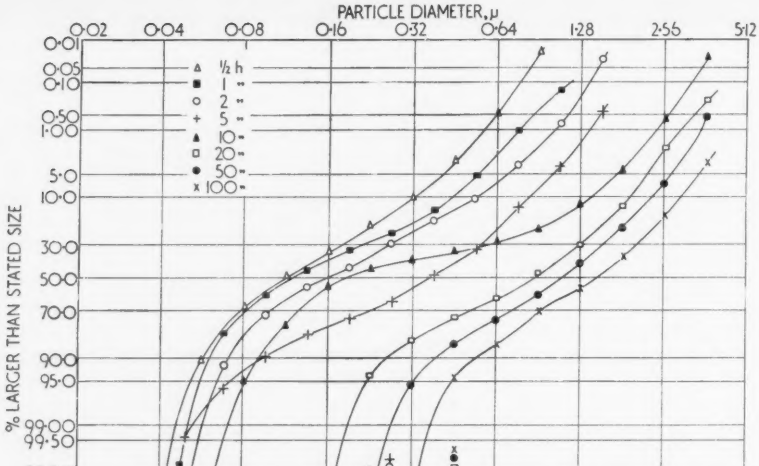


Fig. 9—Size-frequency distributions of carbide spheres produced by tempering 0·9% C steel at 700° C

The effect of composition on the ferrite grain size was not very marked; it appeared that the ferrite grain size of specimens tempered under the same conditions of time and temperature decreased as the carbon content was increased.

Carbide Particle Size Distributions

The experimentally observed circle diameter distributions of the carbide particles were transformed into the true sphere size distributions using the methods outlined in the Appendix. For each specimen the cumulative particle frequency percentage was then plotted on a probability scale against a $\log_{\sqrt{2}}$ scale of sphere diameter. Typical curves for the 0·9% C steel after tempering for different times at 700° C are shown in Fig. 9.

It will be seen from these graphs that it has been necessary to alter the zero of the abscissæ in many cases where the relative displacement of the curves is small, in order to make the experimental results more clearly distinguishable. Where this has been done, the amount by which the zero has been shifted for a given curve is indicated by the position along the abscissa of an appropriately labelled arrow relative to a constant reference point, chosen for convenience to be at $\phi = 10$. This upper arrow indicates the point on the abscissa to which the point on the scale indicated by the value $\phi = 10$ was moved for plotting the curve.

By their progressive displacement in the direction of increasing particle size, the cumulative frequency % curves shown in Fig. 9 illustrate the gradual coarsening of the carbide dispersion of the steel which occurs during tempering at constant temperature. At the same time, there is a corresponding increase in the range of sizes over which the distributions spread, and a change in the character of the distributions from the reverse-J type which is obtained in the initial stages to one more nearly approaching the log-normal type in the later stages. The higher the tempering temperature is, the more rapidly these changes occur.

Changes in Size of Individual Particles

There is one type of quantitative result which may be obtained directly from the cumulative frequency % curves of the type shown in Fig. 9.

Consider a specimen tempered at 700° C for 100 h, for which it is known that there are 100 particles in a volume $V_1\mu^3$. The largest 10% of these, i.e. the 10 particles above a size u_1 in this volume $V_1\mu^3$, must have been the 10 largest particles in the same volume of matrix when the specimen had been tempering for only 50 h, for example. Suppose that it is known, from measurements made on a specimen at this stage of tempering, that 100 particles occur in a volume $V_2\mu^3$, where $V_2 < V_1$. Then the 10 largest particles at the 50-h stage in a volume $V_1\mu^3$ represent 10 V_2/V_1% of the total number of particles. From the known cumulative frequency % curve for the specimen, it can be determined that this percentage comprises all particles of, say, size u_2 and larger.

Hence a particle of size u_1 after 100 h tempering is found to have been of a size u_2 after 50 h tempering. By continuing the process for the cumulative frequency % curves obtained for the other times, and by repeating the whole operation choosing different values of initial particle size, a family of curves can be constructed which shows the variation in size of individual particles with tempering time at constant temperature in a given steel. Figure 10 shows the case of the 0·9% C steel, tempered at 700° C. It will be seen that only the particles which have grown to the largest size after ½ h will still be growing after 100 h. Below this size, they grow for a time and later begin to dissolve. The smaller they are at ½ h, the sooner solution starts,

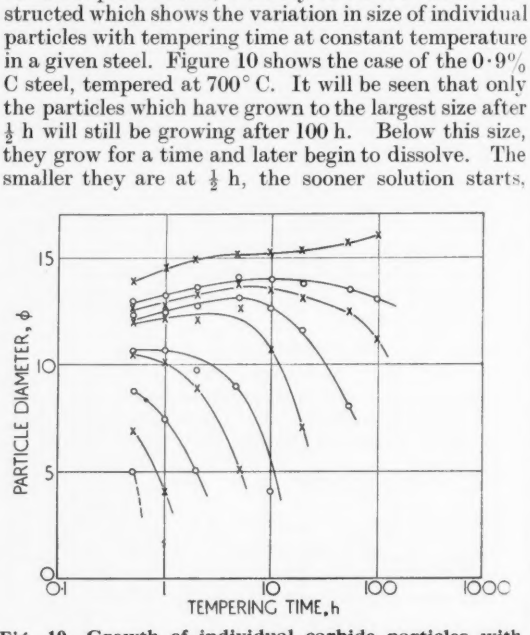


Fig. 10—Growth of individual carbide particles with progressive isothermal tempering of 0·9% C steel at 700° C

while the smallest sizes observed at ½ h are already in the process of solution.

Parameters of the Distributions

The parameters of the distributions may be plotted against the tempering time and temperature, but more informative results are obtained by plotting them against the corresponding hardness value of the microstructure examined. Figures 11 and 12 show the variation of the number of particles per unit volume ($1\mu^3$) and of the mean particle diameter when plotted against the corresponding hardness values. The curves clearly show how, as the steel softens during tempering, the number of particles decreases and their mean diameter increases. It is also seen that for any given steel the points lie on a single curve. This suggests that a given hardness is characterized by a given microstructure, independently of the time–temperature treatment used to produce this hardness. However, the carbon content of the steel is important, since varying the composition produced a family of curves. Similar relationships are found between the mean particle spacing and the hardness (Fig. 13).

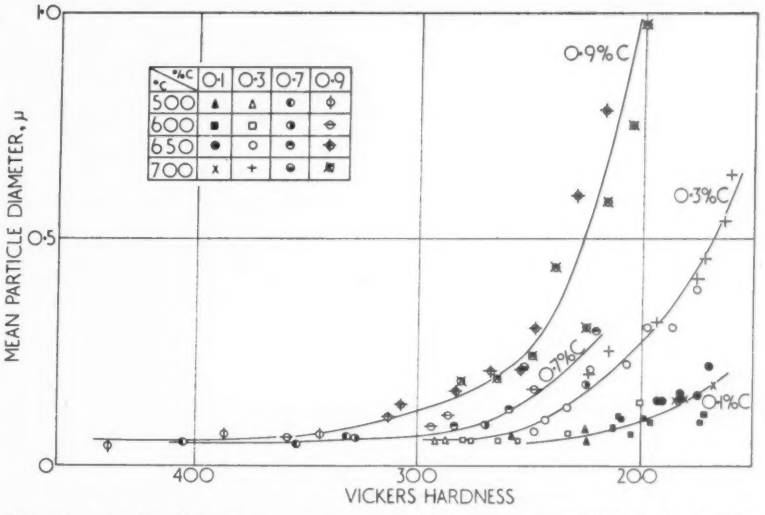


Fig. 12—Relationship between mean particle diameter and Vickers hardness

The values of the mean spacings S between the particles were calculated for Fig. 13 from the relationship:

$$S = (1 - f)\, N^{-1/3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where f is the observed volume fraction of the carbide and N is the experimental value for the corresponding number of carbide particles in a volume $1\mu^3$ of steel. This expression is simply derived. The volume of matrix associated with each particle $= 1/N\mu^3$. Considered as a cube, this volume is of side $= N^{-1/3}\,\mu$. If a line penetrates this cube perpendicular to a face, the relative length intercepted by the carbide phase is f and by the ferrite $(1 - f)$.

Hence the actual length of intercept through the ferrite is $(1 - f)\, N^{-1/3}$. This is the mean surface–surface distance between the carbide particles.

From a knowledge of the particle size distribution it is possible to calculate the volume fraction of the carbide. The values calculated in this way were consistently larger than those calculated from the carbon content of the steel. However, this discrepancy became less as the coarseness of the particles increased.

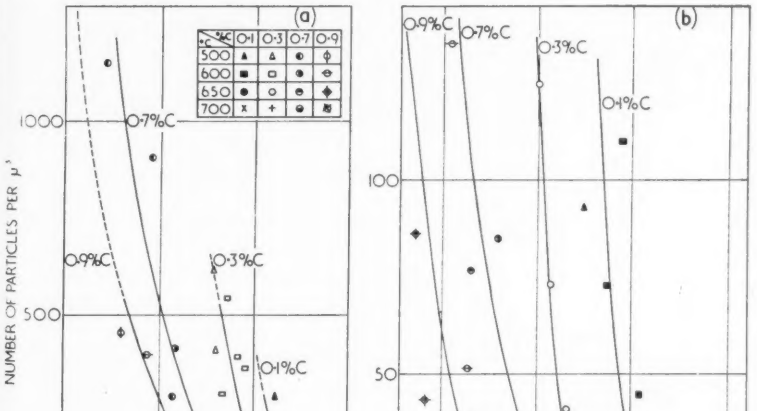


Fig. 11—Relationship between number of particles/μ^3 and Vickers hardness

DISCUSSION

The experimental results given above shed further light on two important and quite distinct problems, namely, the kinetics of the fourth stage of tempering and the relation between the microstructure and the mechanical properties of the structures produced. Following an evaluation of the accuracy of the measurements, therefore, these two aspects of the tempering process are treated separately.

Accuracy of the Particle Size Distributions

The use of a $\sqrt{2}$ progression of size intervals for measuring the distributions has several advantages. The error involved in assigning a particle

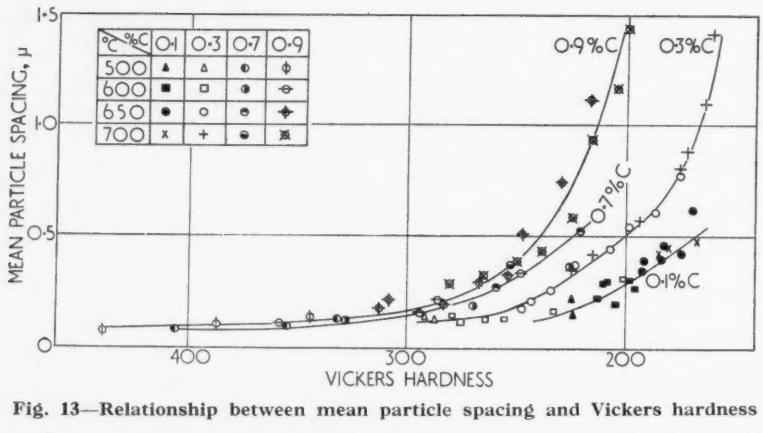


Fig. 13—Relationship between mean particle spacing and Vickers hardness

to the wrong size-group is relatively small, whilst a very large size-range can be covered by a conveniently small number of size-groups. Furthermore, estimation of particle size by visual comparison with a graticule of this type is precise and quick over the whole range, because the areas of successive circles differ from each other by a large and constant factor.

Five possible errors likely to influence the results are: (i) in sampling, (ii) in replication of the structures, (iii) in estimating the electron optical magnification, (iv) in transforming the observations to give the sphere distributions, and (v) in estimating the depth of etch of the specimens. As it is not possible to compensate individually for these errors, a blanket correction was devised to estimate the total effect these errors may have had on the results. Since the net effect was likely to have been an over-estimation of the size of individual particles, the observed particle frequencies have been retabulated by assigning each observed frequency to the next lower size-group. New sphere distributions were then calculated and new parameters derived from them.

When the new parameters were plotted against the corresponding hardness values, a consistent displacement of the points occurred, as would be expected, but the new values were within or near to the experimental scatter of the original values. The effects of applying the correction to values for the mean particle spacing are shown in Fig. 14. It may be concluded, therefore, that any errors in particle-size measurement will not have affected substantially any of the results described.

Kinetics of the Fourth Stage of Tempering

The curves of Fig. 10 throw more light on the well-known process of simultaneous particle solution and growth by which isothermal coarsening of two-phase aggregates is seen to occur. A possible mechanism for this process has been discussed by Cottrell and Leak.[26] It is reasoned that the carbon content of the matrix will be greater in the region of the smaller particles than of the larger ones. Consequently, there will be diffusion of carbon along the concentration gradients through the matrix, leaving the ferrite in the region of the smaller particles unsaturated with regard to carbon and rendering the ferrite supersaturated in the region of the larger particles. The smaller particles would then go into solution and the larger particles would grow still larger by precipitation of carbide from the matrix.

If this mechanism alone accounts for the changes in carbide particle size, then the rate-controlling process would appear to be the diffusion of carbon in α-iron, the activation energy of which is known to be $\simeq$ 20 kcal/g-mol. From the data obtained in this investigation it is difficult to estimate the activation energy for particle growth. Stibe,[27] however, has recently derived a mathematical technique for calculating the expected size distribution of particles after isothermal tempering, when starting from a given particle size distribution in a matrix and assuming that re-solution and growth is the mechanism of coarsening. Applying this mathematical technique to the results obtained in the present investigation, Stibe found agreement between calculated and observed particle size distributions, if he assumed the rate-controlling process had an activation energy of 60 kcal/g-mol.

Previous authors have assumed that changes in particle size or particle separation are directly responsible for changes in hardness; the activation energy for the softening of tempered steel would be expected, therefore, to correspond to the activation energy for carbide particle growth. As is shown in Table IV, however, the activation energy for softening is $\simeq$ 60 kcal/g-mol; similar values have been given by Hollomon.[11] In view of these high values for the activation energy, it must be assumed that the rate-controlling process for softening is the self diffusion of α-iron, which is known to have an activation energy of $\simeq$ 60 kcal/g-mol.

On the other hand, measurements of the activation energy associated with the quench ageing of low-carbon steels agree with the accepted values for the activation energy for diffusion of carbon in α-iron. Similarly, for short-time low-temperature tempering of carbon steels, values for the activation energy of softening of $\simeq$ 12 kcal/g-mol have been obtained by Hollomon and Jaffe[11] and Roberts *et al.*[28]

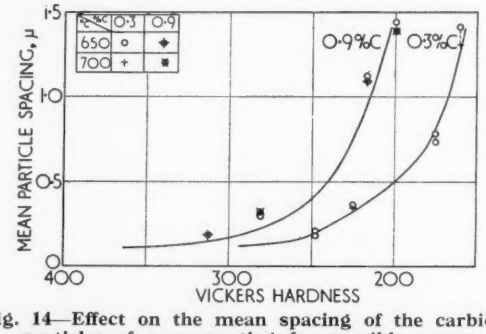


Fig. 14—Effect on the mean spacing of the carbide particles of compensating for possible errors in the particle size analysis

It appears therefore that, in the case of plain carbon steels, there are differences in mechanism between the initial and the final stages of the tempering process. These differences must result from the fact that, in the early stages of tempering or ageing, the majority of the carbide particles are coherent with the matrix and are growing larger by depleting the surrounding matrix of carbon; but, in the fourth stage of tempering, only a few of the carbide particles are growing larger and the majority are going back into solution and all are non-coherent. The high activation energy for particle growth during the fourth stage of tempering can be explained as follows: the transformation from cementite into ferrite involves an increase in density, and thus the net effect of transferring iron atoms from the cementite to ferrite lattice positions will be the production of vacancies. These vacancies will have to diffuse away before the cementite particles can go further into solution. Similarly, vacancies must diffuse to, and be annihilated at, the growing cementite particles. The movement of vacancies may therefore be the rate-controlling process, and this would require an activation energy for self diffusion.

There is, however, another possible explanation of why the rate-controlling process for softening is the activation energy for self diffusion of α-iron; this is discussed in the next section.

Relation between Microstructure and Hardness

The changes in hardness which occur during tempering can be treated as a function of time and temperature or as a function of the microstructure. The first method of approach, while possessing merits of its own, is at present purely empirical. Nevertheless, the second method of approach is the more fundamental. This is supported by the conclusion, which may be drawn from the continuous variation with hardness of the parameters of the carbide distributions for each steel, that, for a given steel, time–temperature tempering treatments which produce the same hardness also produce the same microstructure.

A simple statement of the relation between hardness and microstructure in two-phase alloys made by O'Neill[29] is that the hardness is proportional to the relative amounts of the two phases present. This

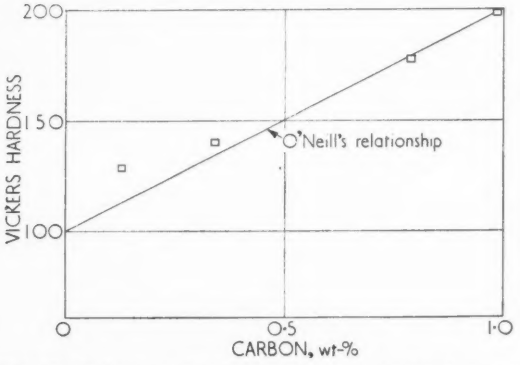


Fig. 15—Influence of composition upon the hardness of alloys of the system Fe–Fe_3C (from the relationship proposed by O'Neill), compared with the lowest Vickers hardness produced by the tempering of the 0·1, 0·3, 0·7, and 0·9% C steels

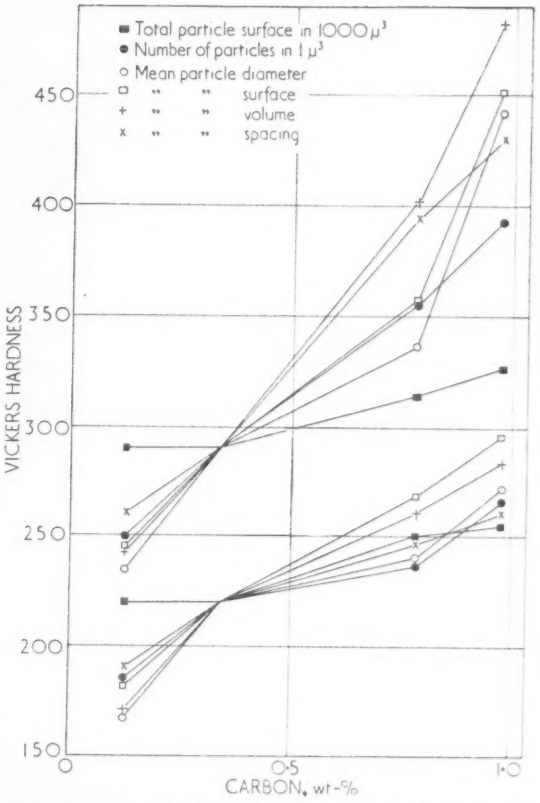


Fig. 16—Variation with steel composition of the hardness shown by microstructures having the same values of individual parameters of the particle distributions as those possessed by a 0·3% C steel tempered to a Vickers hardness of 220 and 290

implies that the hardness of a steel decreases on tempering to a minimum value which is dependent upon the carbon content. When the hardness of the softest specimen produced in each steel in this investigation is plotted as in Fig. 15 against the carbon content of the steel, it is seen that the points do in fact lie close to the straight line between the hardness of ferrite (100 Vickers) and cementite (800 Vickers), which represents the relationship of O'Neill.[29] However, the data of Figs. 7 (*a*)–(*d*) do not indicate that an ultimate 'minimum hardness' can ever be reached. It seems that the size of the indenter impression relative to the strueture introduces a problem of its own in very coarse structures. Hardness must therefore be related to the more fundamental variables of microstructure which may be involved. Here, these may be the amount and degree of dispersion of the carbide phase, the ferrite grain size, and the intrinsic hardness of the carbide particles and of the ferrite matrix; the distribution of the carbide particles and the ferrite grain size may be interdependent.

At this point, it is possible to eliminate one way in which the volume fraction of carbide, the particle size distribution, and the hardness could be related. It could be supposed that two steels differing in carbon content could have identical particle size

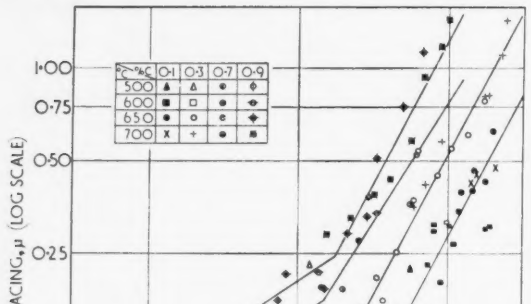


Fig. 17—Relationship between the log of the mean participle spacing and the Vickers hardness

distributions at similar stages of tempering, but have different hardnesses since the respective total amounts of carbide in unit volume are not the same. In this event, some parameters of the distributions would be identical (e.g. mean diameter, surface, volume, and spacing), but others (e.g. number of particles per μ^3 and total particle surface in $1000\mu^3$) would not.

Figure 16 shows the variation with steel composition of the hardness shown by microstructures having the same values of individual parameters of the particle distributions as possessed by a 0·3% C steel at a Vickers hardness of 220 and 290. The supposed identity of some parameters is not observed; the different sets of points all lie on separate curves. Figure 16 therefore shows that the original supposition is incorrect and that carbon steels of different composition never have the same particle size distribution at any stage of the tempering process.

The effect produced by varying the amount of the dispersed phase was observed by neither Gensamer and co-workers[12] nor Roberts *et al.*[13] for steels, nor by Shaw *et al.*[14] for over-aged Al–Cu alloys. Measurement of the microstructures by these investigators, however, were carried out with the aid of the light microscope and they were therefore limited by the resolution to the coarser distributions, for which the effect of volume fraction is not so marked. The greater accuracy of measurements in the present investigation and the wider range of degree of dispersion available, is responsible for its detection.

The linearity of the relationship derived by Gensamer and co-workers[12] is confirmed in Fig. 17 which shows the variation of the log of the mean particle spacing with hardness, although the results show a fairly large experimental scatter and some deviation from the expected values for the 0·7% C and 0·9% C steels at higher hardnesses. However, the dependence of hardness on the volume fraction of carbide, which was not observed by Gensamer and co-workers,[12] is well marked here.

In Fig. 18, in which the reciprocal of the mean particle spacing is plotted against hardness, the predicted linearity of the relationships put forward by Bragg,[18] Mott and Nabarro,[19] and Orowan[20] is not strictly obeyed. The curves again demonstrate a variation of hardness with volume fraction of carbide, which is not predicted by theory.

The expression derived by Fisher, Hart, and Pry[22] and given in equation (3) is the only theoretical one available at present in which the hardness is expressed as a function both of a parameter of the particle size distribution and of the volume fraction of the particles.

Since hardness is approximately a linear function of tensile strength, equation (3) becomes:

$$r \propto \frac{f^{3/2}}{(H - H_{a\text{–Fe}})} \qquad \ldots\ldots (7)$$

where H is the hardness of the specimen, $H_{a\text{–Fe}}$ is the hardness of the ferrite matrix, and r is the mean radius of the particles intersected on the slip plane.

In representing this relation in Fig. 19, the values of r and H have been taken from the smooth curves through the experimental points shown in Fig. 12 and the values of the volume fraction f have been calculated from the known chemical compositions. $H_{a\text{–Fe}}$ was taken to be 100 Vickers. The resulting smooth curves show that the theoretically derived relationship once more does not take into account completely the effect of the carbon content of the steel. This effect is clearly marked, even if actual experimental values of r and f are used, although the scatter of the plotted points is then much greater.

In Fig. 20 the relation developed by Unckel[23] (equation 4) has been tested by plotting the mean particle spacing against the log of the parameter $\frac{H - H_{a\text{–Fe}}}{H_c - H_{a\text{–Fe}}}$. Here H is the hardness of the tempered steel, H_{a-Fe} that of the ferrite matrix, and H_C that of the cementite particles themselves. The resulting curve should then be a straight line of slope equal to the coefficient, $-B$, of the exponent in Unckel's expression. However, the plotted points in

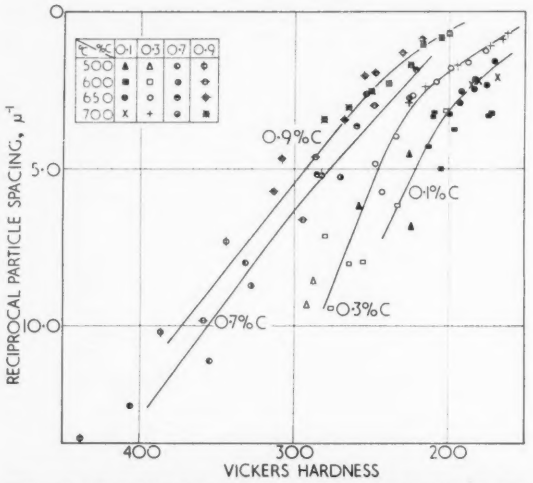


Fig. 18—Relationship between the reciprocal of the particle spacing and the Vickers hardness

fact lie on four well-defined curves, corresponding to the carbon contents of the four steels used. It is evident that, as a complete expression of the dependence of hardness on the carbide particle distribution, Unckel's expression is scarcely more successful than the others previously considered.

The theoretical considerations upon which the data shown in Figs. 18–20 have been based are limited in their practical applications by the various simplifying assumptions which have had to be made by their respective authors. The relations proposed by Bragg,[18] Mott and Nabarro,[19] and Orowan[20] postulate a uniform value of the particle spacing; that by Fisher, Hart, and Pry[22] supposes a uniform size of the circular sections of the particles in the slip-plane. In practice, neither of these conditions occur. In addition, these relationships all predict zero strength for the matrix when the dispersion is infinitely coarse.

Unckel's[23] relationship on the other hand does predict finite values of the strength both of the dispersed phase and of the matrix. These must find expression in any detailed analysis of the relation between hardness and microstructure, not only because their absolute values influence the hardness of the aggregate but also because their relative values will determine the type of deformation which will occur under given conditions.

The influence of ferrite grain size in relation to the mechanical properties of tempered steels has not been discussed by previous workers. It is, however, well

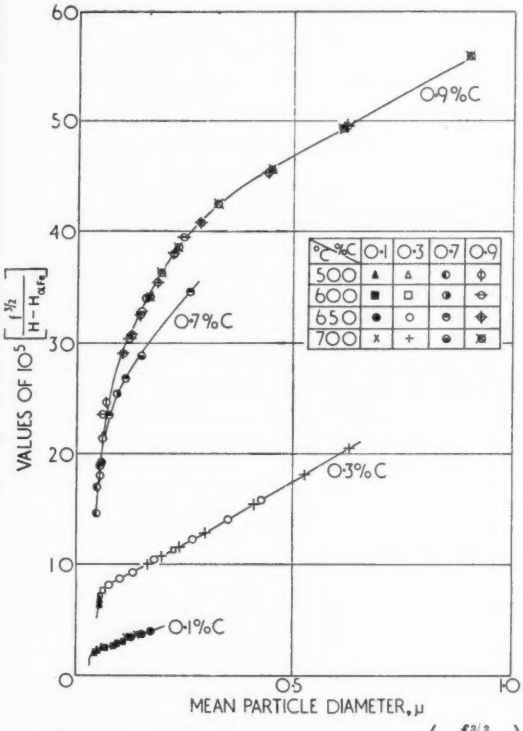


Fig. 19—Relationship between the quantity $\left(\frac{f^{3/2}}{H-H_{\alpha\text{-Fe}}}\right)$ derived by Fisher, Hart, and Pry, and the mean particle diameter

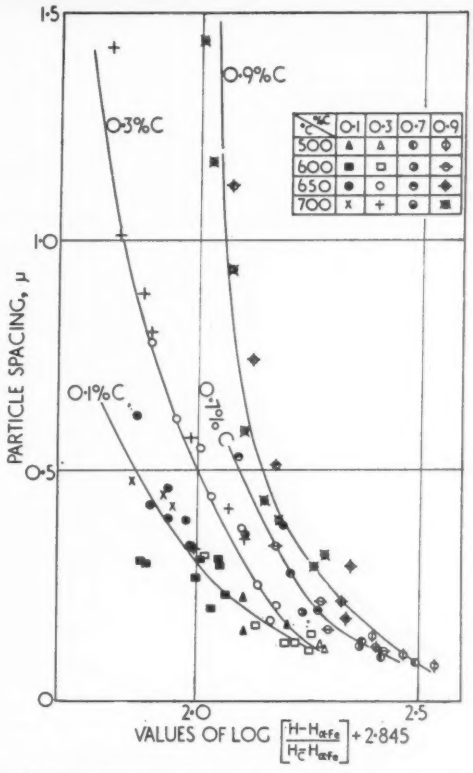


Fig. 20—Relationship between particle spacing and log of the quantity $\left(\frac{H-H_{\alpha\text{-Fe}}}{H_c-H_{\alpha\text{-Fe}}}\right)$ derived by Unckel

known that changes in mechanical properties result from changes in the grain size of pure metals or single-phase alloys. A quantitative relationship for the influence of grain size upon hardness has recently been derived by Hall[30] who has shown that:

$$\text{Hardness} \propto \frac{1}{\sqrt{\text{Grain Diameter}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

In the steels tempered for a long time at high temperatures, where the microstructure may be clearly resolved, it may be seen that the particles of cementite are almost exclusively at the boundaries of the ferrite grains. At lower temperatures and after shorter times, the ferrite grain boundaries are not clearly etched or resolved, but it may be assumed that a somewhat similar structure of particles at the grain boundaries is present. If this is the case, it is possible to calculate the ferrite grain size by using the formula derived by Smith[31]:

$$\frac{R}{r} = \frac{3}{4f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

where R = mean radius of curvature of the grain boundaries, r = mean radius of curvature of the particles, and f = volume fraction of the particles present in the matrix.

Since the mean radius of curvature of the particles and their volume fraction are known, it is possible to calculate the mean radius of curvature of the grains. If the grains are assumed to be spherical, then R will correspond to the grain radius.

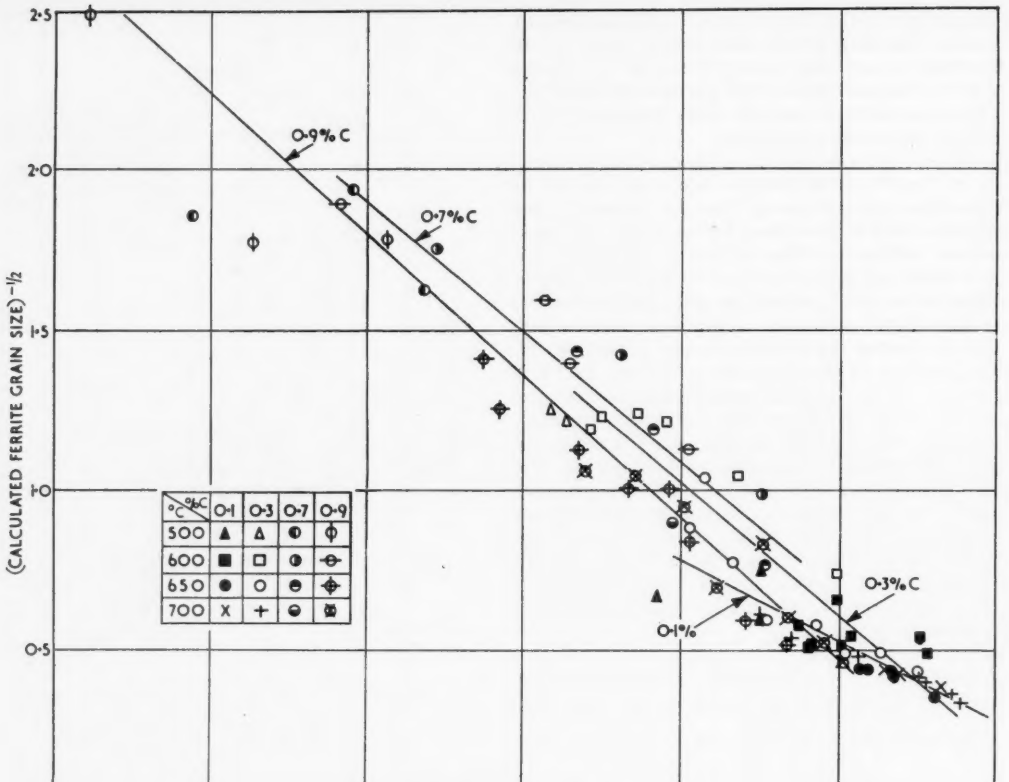


Fig. 21—Relationship between (calculated ferrite grain size)$^{-½}$ and Vickers hardness

In Fig. 21 it is shown that there is a linear relationship between the hardness and the reciprocal of the square root of the calculated grain diameter, and over the range of carbon contents investigated all the points tend towards the same straight line. In view of this relationship it is now possible to propose a mechanism for the fourth stage of tempering. After the formation of cementite from ε-iron carbide, the ferrite matrix recrystallizes. Grain growth is, however, hindered by the presence of cementite particles at the grain boundaries. With increasing temperature or time of tempering, the carbide particles grow and so allow the ferrite grains to grow. It is suggested that the hardness of a tempered steel is governed by the grain size attained, and this in turn is a function of the particle size.

The growth of the ferrite grains would be controlled by a mechanism involving the self diffusion of α-iron, and this may account in part for the high activation energies of softening found in this and other investigations. In view of the results obtained by Stibe,[27] however, it appears that particle growth is also controlled by a mechanism involving self diffusion of α-iron; thus grain growth and particle growth are always in step with each other, and the relationship postulated by Smith[31] between the grain size and the particle size is followed.

The significance of the results obtained when determining the Meyer index of tempered steels now becomes apparent. Both Pfeil[32] and O'Neill[33] have shown that the Meyer index of ingot iron is independent of the ferrite grain size. Therefore, if the hardness of carbon steels is controlled by the ferrite grain size, little change in Meyer index would be expected over a wide range of tempering treatments.

In the present investigation it has not been possible to determine the ferrite grain size accurately because of the limitations of the plastic replica technique used for the electron metallography. However, with the development of the carbon replica process by Bradley,[34] there is no doubt that a greatly improved resolving power may be obtained and more accurate measurements of the ferrite grain size can therefore be made. A few preliminary experiments have already been carried out using the carbon replica technique and these have confirmed the importance of ferrite grain size in controlling the properties of plain carbon steels.

CONCLUSIONS

From the present investigation it may be concluded that:

(1) For any one carbon steel, simple isothermal tempering treatments which produce the same hardness also produce the same microstructure.

(2) With increasing carbon content of different steels tempered to the same hardness, the microstructures show a decrease in the number of particles per unit volume and in the total particle surface area and an increase in the mean particle diameter, surface, volume, and surface–surface spacing.

(3) For steels of different carbon contents tempered to the same hardness, the size frequency distribution of the carbide particles is not the same.

(4) The measured activation energy of the tempering process is not equal to that for the diffusion of carbon in α-iron as had been suggested, but corresponds with that of the self-diffusion of α-iron.

(5) It has been possible to calculate the way in which individual carbide particles will change in size during the tempering process. A mechanism is given, which would require the rate-controlling process for particle growth to be the diffusion of vacancies through the α-iron.

(6) A linear relationship has been observed between the Vickers hardness and the reciprocal of the square root of the calculated ferrite grain diameter.

(7) It is suggested that the fourth stage of tempering involves the simultaneous growth of the ferrite grains and the carbide particles. As the carbide particles are at the ferrite grain boundaries, they hinder grain growth, but both particle growth and grain growth occur by the movement of vacancies through the α-iron lattice.

Acknowledgments

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APPENDIX

Determination of the True Sphere Size Distribution

From the Observed Circle Distribution on a Random Plane of Section through a Matrix Containing Dispersed Spheres

If a random plane of section is taken through a matrix containing a dispersion of spheres of uniform diameter, these spheres will be observed as circular sections having diameters ranging from zero to that of the spheres themselves.

The probability of finding circles of diameter between zero and any diameter d less than the diameter of the spheres has been shown by Scheil[35] to be given by the expression:

$$P_D(d) = 1 - \frac{1}{D}\sqrt{D^2 - d^2} \quad \ldots\ldots\ldots\ldots (10)$$

where $P_D(d)$ = probability of finding a circle of diameter between zero and d, when sectioning a dispersion of spheres of diameter D. If the circles are sized in a $\sqrt{2}$ progression of diameters, the probability of finding a circle of a given size group on the plane of section is given in Table V.

When the spheres dispersed in the matrix are not of uniform diameter, the problem of determining the actual size distribution from the observed circle diameter distribution may be solved in the following way, making use of the results obtained when considering a dispersion of spheres of uniform diameter.

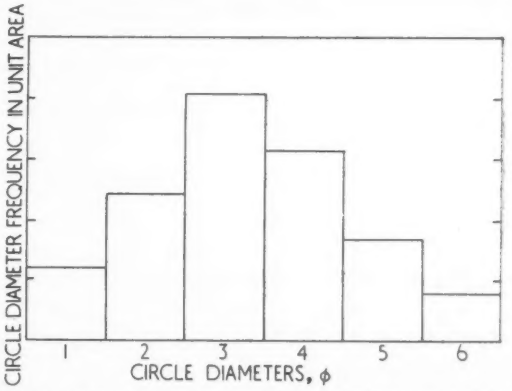

Fig. 22—Histogram representing a distribution of circle diameters observed as a result of sectioning a matrix containing dispersed spheres of non-uniform diameter

Let the distribution of the circle diameters be the histogram shown in Fig. 22. It is now assumed that all the circles in the largest size group ($\phi = 6$) are obtained as a result of sectioning spheres of the same size group close to a diametral plane. However, the total number of spheres of this size group intersected by the plane of section will be larger than the observed number of circles in the size group, since some of the spheres will be sectioned away from the diametral plane, giving circles of smaller diameter than the size group limits.

The total number of spheres in the largest size group will be given by dividing the total number of circles in the largest size group by the appropriate probability factor shown in Table V:

$$N_S\,(\phi = 6) = N_C\,(\phi = 6)/0{\cdot}707 \quad \ldots\ldots\ldots (11)$$

where $N_S(\phi = 6)$ = total number of spheres in size group $\phi = 6$ intersected in unit area of section plane and $N_C(\phi = 6)$ = total number of circles observed in size group $\phi = 6$ in unit area of section plane.

The number of circles in size groups smaller than $\phi = 6$, which originate from the sectioning away from a diametral plane of spheres in size group $\phi = 6$, may now be calculated for each of the smaller size groups. The value is given by multiplying the value $N_S(\phi = 6)$ by the appropriate values of the probability of sectioning shown in Table V.

Now the observed circles in size group $\phi = 5$ originate from the sectioning of spheres in size group $\phi = 6$ and spheres in size group $\phi = 5$.

Since the number of circles in size group $\phi = 5$ originating from the spheres of size group $\phi = 6$ has already been calculated, the number of circles originating from spheres in size group $\phi = 5$ may be obtained. Hence the total number of spheres of size group $\phi = 5$ intersected in unit area of the section plane may be calculated as before, using equation (10). Similarly, the numbers of circles in size groups less than $\phi = 5$ originating from the sectioning away from a diametral plane of spheres of size group $\phi = 5$ may be obtained.

These methods are now re-applied to the circles in

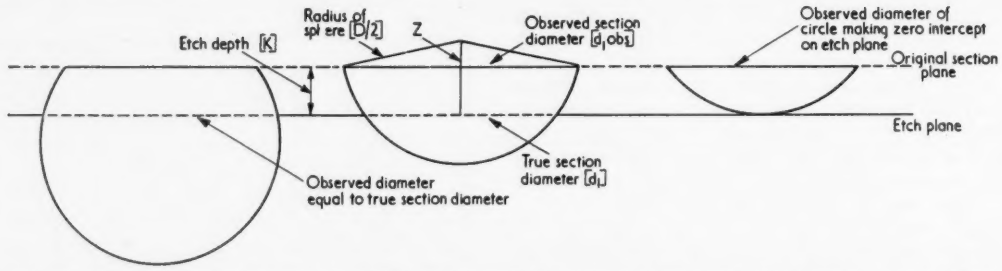
Radius of sphere [D/2]
Z
Observed section diameter [d1 obs]
Observed diameter of circle making zero intercept on etch plane
Etch depth [K]
Original section plane
Etch plane
True section diameter [d1]
Observed diameter equal to true section diameter

Fig. 23—Effect of etching the matrix upon the observed diameters of spheres having their centres above and below the section plane

size group $\phi = 4$ which, it will be seen, originate from the sectioning of spheres of size groups $\phi = 6$, $\phi = 5$, and $\phi = 4$. As the numbers of circles deriving from the two larger sphere size groups have been calculated, the number of circles originating from the spheres of size group $\phi = 4$ may be found, and the total number of spheres of size group $\phi = 4$ can be calculated. The numbers of circles in size groups smaller than $\phi = 4$ coming from spheres of size group $\phi = 4$ may then be calculated as before. This process of calculation is continued for the remaining size groups of the histogram.

The values obtained by this analysis are the numbers of spheres in each size group intersected by unit area of the section plane. The values required are usually the numbers of spheres of each size group in unit volume of matrix. These latter values may be obtained by dividing the former values by the respective sphere diameters.

As a geometrical progression of size intervals is used, each size interval is related to its neighbour by a constant factor. It is therefore necessary to calculate only the probability values shown in Table V. With Scheil's[35] method, which involves an arithmetical progression of size intervals, each interval is related to its neighbour by a different factor, and a different set of probability values has to be calculated for each step of the analysis.

Correction to be Applied after the Section Plane is Changed by Etching

If a new plane of section is produced by etching away the matrix around the particles to a uniform depth parallel to the original plane of section, the circle diameter distribution observed on the new etching plane will differ from that obtained on the original section. There will tend to be an increase in probability of finding circles of large diameter and a decrease in probability of finding circles of small diameter. It is possible to calculate the changes in probability as follows.

Consider first the case of spheres of uniform diameter D dispersed in a matrix, which is first sectioned by a random plane and then etched; if the etching plane is now treated as the plane of section, spheres which are intersected by this plane may be divided into two equal groups—those with their centres above and those with their centres below the plane of section. With those spheres having their centres above the plane of section, the diameters of the observed circles will be greater than the diameters of the true circles of section, as can be seen from Fig. 23. From the geometry of this figure it follows that:

$$z^2 = \left(\frac{D}{2}\right)^2 - \left(\frac{d_1 \text{ obs.}}{2}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

and

$$(z + k)^2 = \left(\frac{D}{2}\right)^2 - \left(\frac{d_1}{2}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

where D = dia. of the sphere, d_1 = dia. of the true circle of section, d_1(obs.) = dia. of the observed circle of section, k = depth of etch, and $z + k$ = height of the centre of the sphere above the plane of section.

On the plane of observation the probability of finding circles of diameter between zero and d_1(obs.) must be equal to the probability of finding circles of diameter between zero and d_1 on the plane of section, since one group of circles is directly derived from the other. Using the notation of equation (10)

$$P_D\,(d_1) = P_D\,(d_1 \text{ obs.}) \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

and by eliminating z from equations (12) and (13) it can be shown that:

$$P_D(d_1) = 1 - \frac{1}{D}\sqrt{D^2 - d_1^2} = 1 - \frac{1}{D}\sqrt{D^2 - (d_1 \text{ obs.})^2} - \frac{2k}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

For the general case therefore:

$$P_D\,(d \text{ obs.}) = 1 - \frac{1}{D}\sqrt{D^2 - (d \text{ obs.})^2} - \frac{2k}{D} \quad \ldots\ldots (16)$$

Because of the similarity between equations (10) and (16), it follows that the probability curve for the finding of circles between zero and any diameter less than D on the plane of observation is similar to the probability curve for the finding of circles between zero and any diameter less than D on the plane of section. The former curve is however displaced from

Table V—PROBABILITIES OF OBTAINING CIRCLES IN STATED SIZE RANGE
From the sectioning of spheres of diameter *D*

D–$D/\sqrt{2}$	$D/\sqrt{2}$–$D/(\sqrt{2})^2$	$D/(\sqrt{2})^2$–$D/(\sqrt{2})^3$	$D/(\sqrt{2})^3$–$D/(\sqrt{2})^4$	$D/(\sqrt{2})^4$–$D/(\sqrt{2})^5$	$D/(\sqrt{2})^5$–$D/\sqrt{2})^6$	$D/(\sqrt{2})^6$–$D/(\sqrt{2})^7$	$D/(\sqrt{2})^7$–$D/(\sqrt{2})^8$
0·707	0·159	0·069	0·033	0·016	0·008	0·004	0·002

Table VI—PROBABILITY OF FINDING CIRCLES IN STATED SIZE RANGE
From the sectioning of spheres of varying diameters: etch depth 0·05μ

Circle Diameter Size Group Limits	Probability Values						
	Median Sphere Diameter, μ						
	2·56	1·81	1·28	0·91	0·64	0·45	0·32 and less
D–$D/\sqrt{2}$	0·727	0·735	0·748	0·762	0·785	0·817	0·854
$D/\sqrt{2}$–$D/(\sqrt{2})^2$	0·159	0·159	0·159	0·159	0·149	0·111	0·080
$D/(\sqrt{2})^2$–$D/(\sqrt{2})^3$	0·069	0·069	0·063	0·047	0·035	0·035	0·035
$D/(\sqrt{2})^3$–$D/(\sqrt{2})^4$	0·029	0·021	0·016	0·016	0·016	0·016	0·016
$D/(\sqrt{2})^4$–$D/(\sqrt{2})^5$	0·008	0·008	0·008	0·008	0·008	0·008	0·008
$D/(\sqrt{2})^5$–$D/(\sqrt{2})^6$	0·004	0·004	0·004	0·004	0·004	0·004	0·004
$D/(\sqrt{2})^6$–$D/(\sqrt{2})^7$	0·002	0·002	0·002	0·002	0·002	0·002	0·002
$D/(\sqrt{2})^7$–$D/(\sqrt{2})^8$	0·001	0·001	0·001	0·001	0·001	0·001	0·001

the latter on the ordinate by an amount of $-2k/D$. Therefore, in the largest size group the probability of finding circles will be increased by $2\,k/D$, whilst no circles will be observed having a dia. less than

$$d \text{ obs.} = 2\sqrt{\frac{kD}{15} - k^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Equation (17) corresponds to the case when the true circle of section has zero diameter; this is illustrated in Fig. 23. In the size groups intermediate between these two limiting values, the probability of finding circles on the plane of observation will be unaffected by the etching treatment.

It now becomes possible to calculate the probabilities of finding circles in any size range for the spheres of diameter D which are sectioned so that their centres are above the plane of section. For the 50% of the spheres, sectioned so that their centres are below the plane of section, the probabilities will be the same as those shown in Table V. By taking the mean of these two values for each size range, the probabilities of finding circles on the plane of observation will be obtained.

To calculate the true sphere size distribution from the observed circle size distribution, the same technique is used as before but with the modified probability values. For each sphere size considered, however, the value of the term $2\,k/D$ will change; hence the probability values have to be calculated separately for each stage of the transformation.

The probability values required for the size ranges considered in the present investigation have been calculated assuming an etch depth of 0·5μ. These values are given in Table VI.

References

1. S. Epstein: "The Alloys of Iron and Carbon," vol. 1: 1936, New York, McGraw-Hill Book Co., Inc.
2. K. H. Jack: *J. Iron Steel Inst.*, 1951, vol. 169, pp. 26–36.
3. K. H. Jack: *Ibid.*, 1952, vol. 170, pp. 254–255.
4. W. S. Owen: *Ibid.*, 1954, vol. 177, pp. 445–449.
5. J. Trotter and D. McLean: *Ibid.*, 1949, vol. 163, pp. 9–13.
6. B. S. Lement, B. L. Averbach, and M. Cohen: *Trans. Amer. Soc. Metals*, 1954, vol. 46, pp. 851–881.
7. B. S. Lement, B. L. Averbach, and M. Cohen: *Ibid.*, 1955, vol. 47, pp. 291–313.
8. E. C. Bain: "Functions of the Alloying Elements in Steel," pp. 230–274: 1943, Cleveland, Ohio, American Society for Metals.
9. C. R. Austin and B. S. Norris: *Trans. Amer. Soc. Metals*, 1938, vol. 26, pp. 788–846.
10. E. H. Engel: *Ibid.*, 1939, vol. 27, pp. 1–17.
11. J. H. Hollomon and L. D. Jaffe: *Trans. Amer. Inst. Min. Met. Eng.*, 1945, vol. 162, pp. 223–249; *Metals Technology*, Tech. Publ. No. 1831.
12. M. Gensamer *et al.*: *Trans. Amer. Soc. Metals*, 1942, vol. 30, pp. 983–1019.
13. C. S. Roberts, R. C. Carruthers, and B. L. Averbach: *Ibid.*, 1952, vol. 44, pp. 1150–1157.
14. R. B. Shaw *et al.*: *Ibid.*, 1953, vol. 45, pp. 249–274.
15. M. Gensamer: *Ibid.*, 1946, vol. 36, pp. 30–60.
16. W. A. Wood: *Phil. Mag.*, 1930, vol. 10, pp. 1073–1085.
17. Von S. Shimura and H. Esser: *Stahl u. Eisen*, 1930, vol. 50, pp. 1674–1675.
18. W. L. Bragg: "Symposium on Internal Stresses in Metals and Alloys," pp. 221–226: 1948, London, Institute of Metals.
19. N. F. Mott and F. R. N. Nabarro: "Strength of Solids," pp. 1–19: 1948, London, The Physical Society.
20. E. Orowan: "Symposium on Internal Stresses in Metals and Alloys," pp. 451–453: 1948, London, Institute of Metals.
21. N. P. Allen: "Symposium on Metallurgical Applications of the Electron Microscope," pp. 15–16: 1950, London, Institute of Metals.
22. J. C. Fisher, E. W. Hart, and R. H. Pry: *Acta Met.*, 1953, vol. 1, pp. 336–339.
23. H. A. Unckel: *Metall*, 1951, vol. 5, pp. 146–150.
24. H. A. Unckel: *Metallurgia*, 1952, vol. 45, pp. 115–120.
25. A. R. Entwisle: *J. Iron Steel Inst.*, 1951, vol. 169, pp. 36–38; P. B. Hirsch: *Ibid.*, p. 38.
26. A. H. Cottrell and G. M. Leak: *Ibid.*, 1952, vol 172, pp. 301–306.
27. L. Stibe: Private communication.
28. C. S. Roberts, B. L. Averbach, and M. Cohen: *Trans. Amer. Soc. Metals*, 1953, vol. 45, pp. 576–599.
29. H. O'Neill: *J. Iron Steel Inst.*, 1953, vol. 173, pp. 404–405; vol. 174, p. 351.
30. E. O. Hall: *Nature*, 1954, vol. 173, pp. 948–949.
31. C. S. Smith: *Trans. Amer. Inst. Min. Met. Eng.*, 1948, vol. 175, pp. 15–51; *Metals Technology*, Tech. Publ. No. 2387.
32. L. B. Pfeil: *Carnegie Scholarship Memoires*, Iron and Steel Institute, 1926, vol. 15, pp. 319–379; 1927, vol. 16, pp. 153–210.
33. H. O'Neill: *J. Iron Steel Inst.*, 1929, vol. 120, No. II, pp. 207P–233P.
34. D. E. Bradley: *J. Inst. Metals*, 1954, vol. 83, pp. 35–38.
35. E. Scheil: *Zeitschrift für Anorganische und Allgemeine Chemie*, 1931, vol. 201, pp. 259–264.

The Stress-corrosion Cracking of Austenitic Stainless Steels

By J. G. Hines and T. P. Hoar

Part II—FULLY SOFTENED, STRAIN-HARDENED, AND REFRIGERATED MATERIAL

SYNOPSIS

Fully softened 18–8 chromium–nickel steels stressed in tension and exposed to aqueous magnesium-chloride (42 wt-% $MgCl_2$) solution at 154° C gave stress-corrosion cracking qualitatively similar to that previously found (Part I) for the same steels in the 'as-received' (fully softened and slightly cold-worked) condition. However, certain duplex steels that fractured at zero applied stress in the 'as-received' condition did not fracture at applied stresses less than about two-thirds of the 0·1% proof stress when fully softened.

Plastic strain or sub-zero treatment applied to fully-softened plain 18–8 steel reduced the time to fracture at any particular applied stress and increased the density of cracking. The quasi-martensite formed by either treatment probably provides especially active surface regions for the initiation of stress-corrosion cracks, but plays little part in crack propagation. 1221

Introduction

IN PREVIOUS PAPERS[1, 2] we have described the stress-corrosion cracking of a number of 18–8-type austenitic stainless steels in boiling aqueous magnesium-chloride (42 wt-% $MgCl_2$) solution, and have discussed its general mechanism. The materials used were in wire form, and in the as-received condition had been commercially fully softened but slightly cold-worked by subsequent coiling and uncoiling. In the work now reported, we have examined the behaviour of materials fully softened in the laboratory after uncoiling, of deliberately strain-hardened materials, and of refrigerated materials treated at −184° C.

Several workers have examined the influence of plastic deformation on the stress-corrosion cracking of austenitic stainless steels; the data are, however, scanty and complex. Franks, Binder, and Brown[3] obtained an apparent threshold stress of 38,500 lb/in² for a fully softened 18–8 type steel (0·2% proof stress 35,000 lb/in²) and found that the threshold stress was increased to 50,000–59,000 lb/in² when the steel was heavily cold-worked (so that the 0·2% proof stress was 126,000 lb/in²). On the other hand, Scheil[4] found stress-corrosion cracking in cold-worked steels under small residual stresses (probably less than 3000 lb/in²)—a susceptibility that could be removed by a softening treatment at 1050° C; and some of the steel wires used in our previous work fractured in the as-received condition (fully softened and slightly strained in coiling and uncoiling) at zero applied stress.[2] Scheil,[4] and Tofaute and Rocha,[5] found that certain steels that cracked at zero applied stress after mild cold-work were resistant to stress-corrosion cracking after more extensive cold-work.

It has long been recognized that many austenitic steels can undergo strain-initiated diffusionless transformation to a magnetic phase at room temperature. Rocha[6] suggested that this phase, called 'quasi-martensite' by Edeleanu,[7] plays an important part in stress-corrosion cracking; this idea was developed by later workers.[7, 8]

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Dr. Hoar is with the Department of Metallurgy, University of Cambridge; Dr. Hines, who was with the Department when this work was carried out, is now with Imperial Chemical Industries, Ltd., Billingham Division.

Table I

MECHANICAL PROPERTIES OF THE STEELS AS RECEIVED AND IN THE FULLY SOFTENED CONDITION

Steel	0·1% Proof Stress, 10^3 lb/in²		U.T.S., 10^3 lb/in²		Elongation on 2 in., %	
	As received	Fully softened	As received	Fully softened	As received	Fully softened
18–8 (*b*)	51·6	43	112	86	66	62
18–8–Ti (*a*)	70·4	44	119	92	29	60
18–8–Ti (*b*)	51·5	42	119	86	61	52
18–8–3Mo (*b*)	72·3	47	138	91	44	68

EXPERIMENTAL TECHNIQUE

Four of the steels (wire 0·02 in. in diameter) used in the earlier work—18–8 (*b*), 18–8–Ti (*a*), 18–8–Ti (*b*), and 18–8–3Mo (*b*)*—were used. After straightening and a suitable heat-treatment—steel 18–8–3Mo (*b*) was heated for 1 h at 1150° C, and the others for ½ h at 1100° C—the specimens were water-quenched, pickled, given any other treatment required, and stored for about 6 days in a desiccated atmosphere, before being tested in boiling (154° C) magnesium-chloride solution containing 42 wt-% $MgCl_2$. Table I lists the mechanical properties of the fully softened steels, together with their similar properties 'as received' for ease of reference.

The heat-treatments were carried out in argon purified by being passed successively over potassium hydroxide pellets, magnesium perchlorate, titanium sponge at 800° C, and magnesium perchlorate, and through a liquid air trap. About 50 specimens were treated at the same time. They were cut from coiled stock, straightened, degreased in carbon tetrachloride, and placed in an unsealed silica tube (internal diameter *c.* ½ in.) to protect them from deformation, especially during quenching. The silica tube containing the specimens was suspended in the main furnace tube, which, together with the ancillary glass apparatus, was evacuated to a pressure of 1 μ or less, and left overnight to out-gas. The apparatus was then pumped out again, filled with purified argon, evacuated once more, and refilled with argon before the furnace was heated; a slow stream of argon was passed through the furnace while it was heating up and was at temperature. When the heat-treatment was completed, the lower plug of the furnace was removed under water, and the specimens were allowed to drop out of the furnace to be water-quenched.

* The analyses of the steels have already been reported.[2]

The specimens were then pickled in an aqueous solution of nitric and hydrofluoric acids (15% HNO_3 and 2% HF) for 5 min at 50° C, washed thoroughly in warm water, rinsed in acetone, and allowed to dry. Immediately after pickling, some specimens were given special treatments; all specimens were then stored in a desiccator until required.

Stress-corrosion tests were conducted in the apparatus previously described[2] on specimens stored at room temperature for 4–10 days; the time to fracture is sensitive to the condition of the initial oxide film,[2] but exposure of pickled specimens to dry air at room temperature for 4 days or more ensures uniformity of their condition in this respect, as shown by preliminary stress-corrosion experiments.

RESULTS AND INTERPRETATION

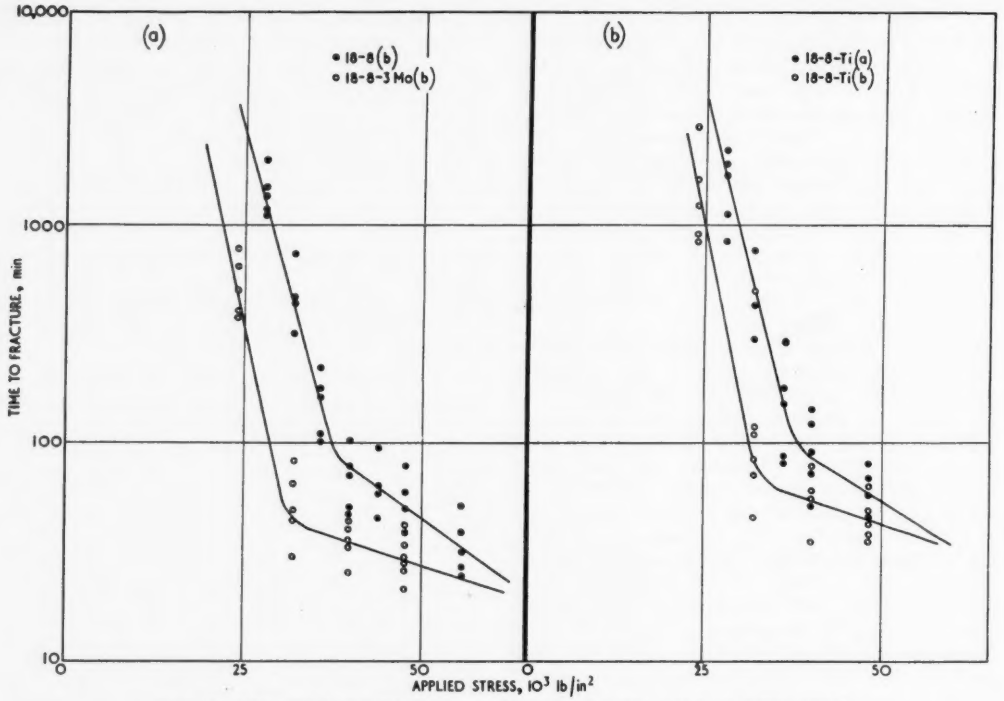
Influence of Applied Stress on the Stress-corrosion Cracking of Fully-softened Steels

The influence of applied stress, S, on the time to fracture, t_f, of ten steels, as received, has already been reported.[2] The relation between S and $\log_{10} t_f$ can be represented by two merging straight lines, and may be characterized by the values of the time $t_{(f)c}$ and the stress, S_c, at which the change in gradient occurs. For the purpose of comparison, it may be more rational to use the ratio between S_c and the 0·1% proof stress, P; the values of this ratio, S_c/P, together with the stresses S_c and P, are included in Table II. The steels as received fall into two groups. Steels 18–8 (*a*) and (*b*), 18–8–LC (*a*) and (*b*), and 18–10–Nb all yield values of S_c/P in the range 0·6–0·75; these steels fractured only after a very long time ($> 10^5$ min), if at all, at zero applied stress. (Steel 18–8–Ti (*a*)—as indicated by the high proof stress and a pronounced ferromagnetic reaction—had clearly been considerably strain-hardened, and shows particularly high values of S_c and S_c/P; it may be a special case.) The remaining steels (18–8–Ti (*b*), 18–8–3Mo (*a*) and (*b*), and

Table II

CHARACTERISTICS OF $\log_{10} t_f/S$ CURVES

Steel	Condition	t_f at Change in Gradient of $\log_{10} t_f/S$ curve, $t_{f(c)}$, min	S at Change in Gradient of $\log_{10} t_f/S$ curve, S_c, 10^3 lb/in^2	0·1% Proof Stress, P, 10^3 lb/in^2	S_c/P
18–8 (*a*)	As received	190	38	52·3	0·73
18–8 (*b*)	As received	160	37	51·6	0·72
	Fully softened	95	39	43	0·90
	Fully softened, then mechanically polished	75	36	43	0·84
	Fully softened, then ½ h at −184° C	75	37	49	0·76
	Fully softened, then pre-strained at 56,000 lb/in^2	70	35	56	0·62
18–8–LC (*a*)	As received	140	31	52·6	0·59
18–8–LC (*b*)	As received	455	32	44	0·73
18–8–Ti (*a*)	As received	345	58	70·4	0·83
	Fully softened	100	37	44	0·84
18–8–Ti (*b*)	As received	85	9	51·5	0·17
	Fully softened	70	33	42	0·79
18–10–Nb	As received	315	29	48·4	0·60
18–8–3Mo (*a*)	As received	—	3	72·0	0·04
18–8–3Mo (*b*)	As received	100	8	72·3	0·10
	Fully softened	45	32	47	0·69
18–10–3Mo–Ti	As received	150	16	52	0·31



(*a*) Steels 18–8(*b*), 153° C; 18–8–3Mo(*b*), 154° C (*b*) Steels 18–8–Ti(*a*), 152° C; 18–8–Ti(*b*), 153° C

Fig. 1—Influence of applied stress on time to fracture of fully softened steels in 42 wt-% $MgCl_2$ solution

18–10–3Mo–Ti), on the other hand, show much lower values of S_c/P; the cracking in these steels was more severe than in the first group, and specimens fractured at zero applied stresses in comparatively short times, presumably because of the presence of local residual stresses caused by quenching or straining.

For the present work on fully softened steels, steels 18–8 (*b*), 18–8–Ti (*a*) and (*b*), and 18–8–3Mo (*b*) were chosen as being representative of the different types of behaviour of the steels as received. Experiments were carried out on these steels, after heat-treatment, over the whole range of applied stress; the relation* between $\log_{10} t_f$ and S is shown in Figs. 1*a* and *b*, and the values of $t_{f(c)}$, S_c, and S_c/P are given in Table II. No specimens fractured at zero applied stress. The values of S_c/P are all between 0·7 and 0·9, although it may be significant that steels 18–8–Ti (*b*) and 18–8–3Mo (*b*), which fractured at zero applied stress as received, show lower values of S_c/P than the other two steels.

The microstructures and the form of the cracking were generally similar to examples previously described.[2] In all the steels the cracks were mainly perpendicular to the direction of applied stress, and showed little branching; but no examples of the very extensive complex cracking typical of steels 18–8–Ti (*b*), 18–8–3Mo (*a*), and 18–8–3Mo (*b*) in the as-received condition were observed.

Thus, the as-received properties of the second group of steels 18–8–Ti (*b*), 18–8–3Mo (*a*) and (*b*), and

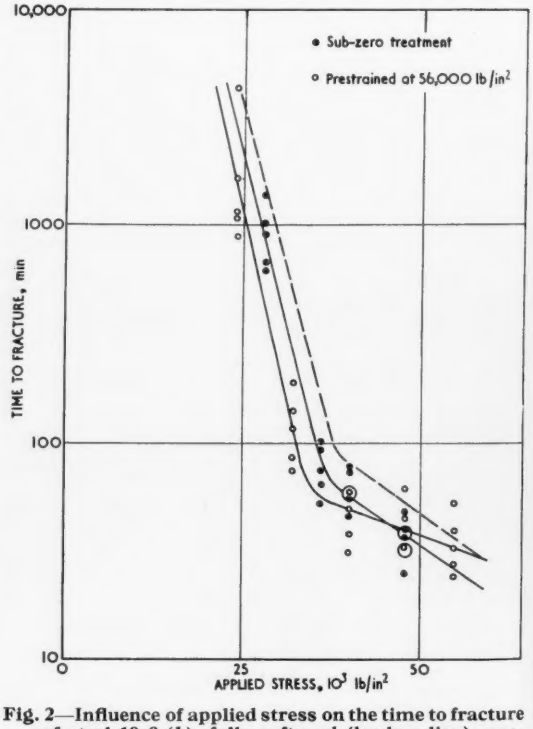


Fig. 2—Influence of applied stress on the time to fracture of steel 18–8 (*b*): fully softened (broken line); pre-strained at 56,000 lb/in^2; and refrigerated at −184° C for ½ h, 152–153° C

* See Part I for similar curves.

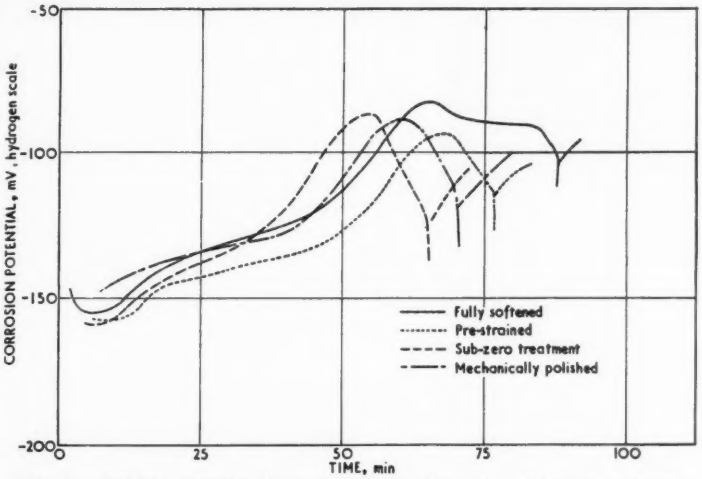


Fig. 3—Typical potential/time curves for steel 18–8 (*b*) after various treatments; 44,000 lb/in², 152–154° C

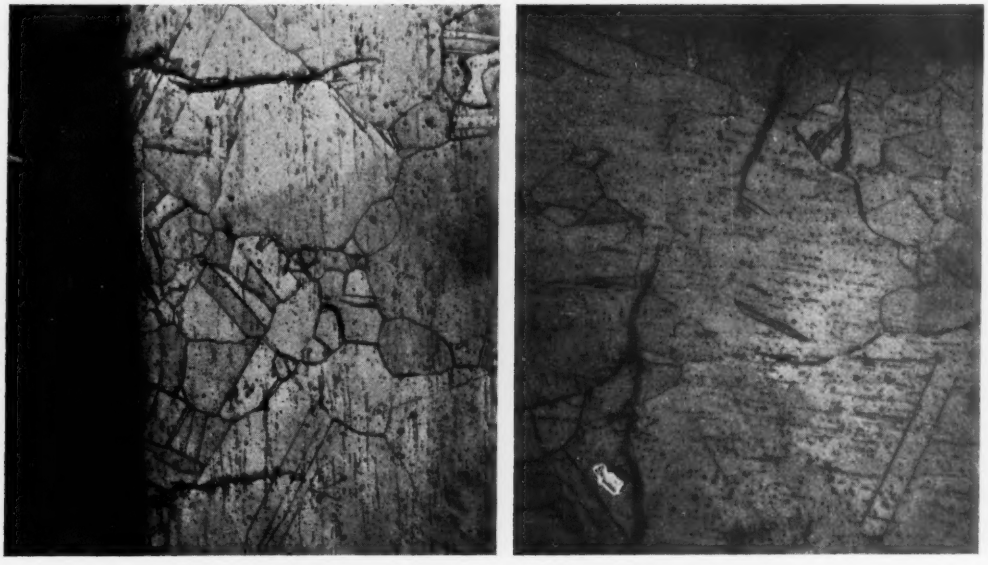
18–10–3Mo–Ti—low values of S_c and S_c/P, fracture in comparatively short times at zero applied stress, and extensive complex cracking—are not exhibited by the representatives of the group (18–8–Ti (*b*) and 18–8–3Mo(*b*)) when fully softened: they then behave very similarly to the first group of steels, whose as-received properties are not greatly changed by the most rigorous softening treatment. Evidently, the second group are much more susceptible to the influence of the small degree of cold-work occurring during the coiling and uncoiling of the wires. It is likely that this susceptibility is caused by their duplex structure, which may well favour the production of disarrayed metal or actual phase-change by strain, and which may also favour the local retention of residual stress owing to the different thermal and mechanical properties of the two phases.

Influence of Previous Plastic Strain and of Sub-zero Treatment

Fully softened specimens of steel 18–8 (*b*) were subjected to one of two types of mechanical strain. One set of specimens was pre-stressed to 56,000 lb/in² (equivalent to *c.* 8% strain) in the testing battery to produce a uniform strain distribution. Another was abraded lightly with 0000 emery and given a mechanical polish with alumina on a Selvyt cloth to produce strain in the surface layers only. A further set of fully softened specimens was immersed in liquid oxygen at − 184° C for ½ h.

The results of time-to-fracture stress-corrosion experiments over the whole range of applied stress are shown in Fig. 2 (to avoid confusion the results for the mechanically polished specimens are not plotted—the $\log_{10} t_f/S$ curve was almost identical with that given by the refrigerated specimens). The values of $t_{f(c)}$, S_c, and S_c/P are given in Table II.

Potential/time curves, taken at representative stresses, were generally similar to those previously obtained on as-received specimens[2, 3]; some typical



(*a*) Fully softened, no quasi-martensite

(*b*) Fully softened and pre-strained at 56,000 lb/in². Note quasi-martensite plates, especially at surface

Fig. 4—Isolated stress-corrosion cracks; steel 18–8 (*b*), 44,000 lb/in², 152–154° C × 250

Fig. 5—Shallow stress-corrosion cracks in steel 18–8(*b*) fully softened and then refrigerated at − 184° C for ½ h; 44,000 lb/in², 152° C ×250

results are shown in Fig. 3. With unstressed specimens, the potential rose to a maximum and then fell slowly with the onset of general film breakdown; the period of film repair, indicated by the time taken to reach the maximum, was not significantly different in the as-received, fully softened, pre-strained, or refrigerated specimens. At low stresses, $< S_c$, all the groups of specimens again gave curves similar to those found with as-received specimens, the rapid potential fall associated with the onset and progress of crack propagation occurring some time after general film breakdown. At higher stresses, pre-straining or refrigeration appreciably shortened the induction period before the onset of cracking: as shown in Fig. 3, at an applied stress of 44,000 lb/in² the onset of crack propagation occurred before that of general film breakdown with the pre-strained and refrigerated specimens, but after with the fully softened.

Examination of specimens after fracture showed that more cracks were produced in the pre-strained and in the refrigerated specimens than in the fully softened. The potential/time curves (Fig. 3) show that the period of rapid crack propagation, t_c, and the extent of the potential fall during crack propagation, were greater for the treated specimens, in harmony with the trend observed when more cracks were present in earlier experiments.[2, 3] The increase in t_c probably reflects the smaller current available for the propagation of each single crack when many cracks are formed, rather than an alteration in the mechanism of crack propagation; and the closely similar behaviour of the pre-strained and the mechanically polished specimens indicates that any quasi-martensite in the *body* of the specimen does not influence crack propagation.

Metallographic examination confirmed the presence of quasi-martensite in the pre-strained and in the refrigerated specimens, and it seems likely that the initiation of cracks is favoured by quasi-martensite regions on the surface. In fully softened specimens the relatively few cracks were mainly isolated (Fig. 4*a*). In the treated specimens (especially those mechanically polished, or refrigerated), although some isolated cracks were found (Fig. 4*b*), many small cracks, confined largely to the surface layers, were present (Fig. 5). Many of these cracks had apparently stopped on reaching a grain boundary. In all the treated specimens, cracks were particularly numerous near the point of ultimate

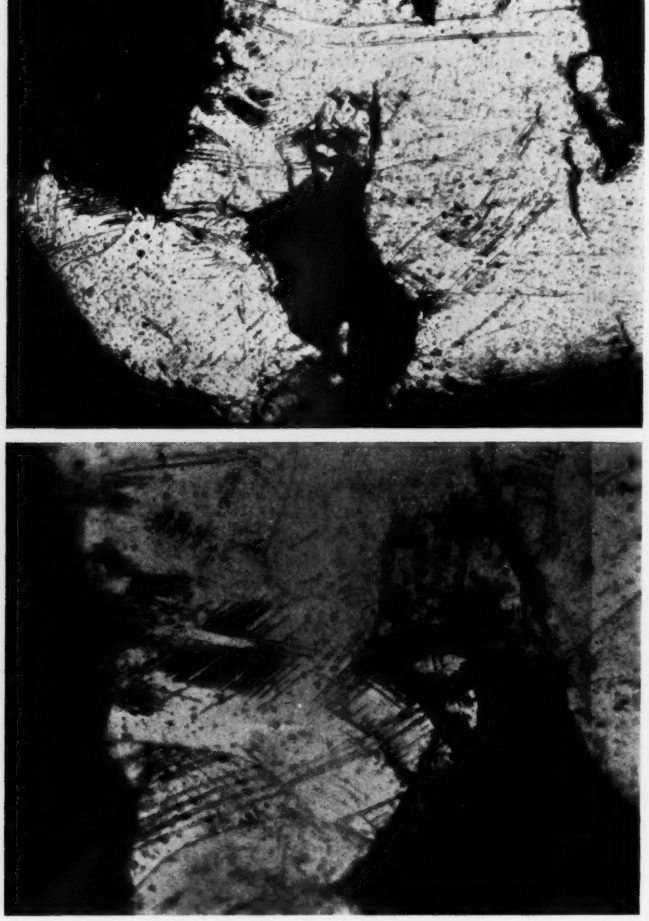


Fig. 6—Extensive cracking and quasi-martensite near the point of fracture in steel 18–8(*b*), fully softened and then refrigerated at − 184° C for ½ h; 44,000 lb/in², 152° C
(*a*) (above) × 250, (*b*) (below) × 750

fracture (Fig. 6*a*)—a tendency noted previously[2] in as-received material. Such regions of particularly dense cracking often contained relatively large quantities of quasi-martensite (Fig. 6*b*); it is unlikely that quasi-martensite could be produced during the cracking process at *c.* 150° C,[9] but it is possible that part was formed during handling after fracture. Cracks did not in general appear to be propagated preferentially in quasi-martensite regions, although there is some evidence (Fig. 7) that cracks tend to follow quasi-martensite plates when these happen to lie in the general direction of cracking imposed by the applied stress. We have previously noted a similar tendency for cracks occasionally to follow suitably directed boundaries between austenite grains.

It may be remarked that results similar to those produced by strain and by refrigeration on steel 18–8 (*b*) may be expected to follow similar, but quantitatively less severe, treatments on the more susceptible group of duplex steels.

DISCUSSION

The present results confirm that the onset of stress-corrosion cracking at 154° C of fully softened 18–8-type steels in 42% aqueous magnesium-chloride solution occurs only after a very long time at stresses almost as high as the 0·1% proof stress[3]; other work now in progress supports this conclusion.[10] It also seems clear from previous work that failures are unlikely in *heavily* cold-worked material at applied stresses less than about half the 0·1% proof stress.[3,4,5] With intermediate amounts of cold work (the usual practical state of affairs) the situation is more complex. The best interpretation of all the data is probably that the stress S_c—which corresponds very roughly to an apparent threshold stress—falls and then rises with increasing amounts of cold work; with some compositions, e.g. those with a pronounced duplex structure in the fully softened condition, or those that form large quantities of quasi-martensite on slight straining (such as 18–8–Ti (*b*)), it may decrease sufficiently with quite small amounts of cold work for fracture at zero applied stress to occur.[2,4,5]

It is thus extremely dangerous to attempt to define, for any 18–8-type steel, a threshold stress below which failure is unlikely to occur in practice. It is true that our values of S_c for fully softened 18–8-type steels (Table II) correspond quite closely with the apparent threshold stress of 38,500 lb/in² found by Franks, Binder, and Brown,[3] and perfectly fully softened material is probably scarcely susceptible to stress-corrosion cracking in hot concentrated chloride solutions at applied stresses less than, say, 25,000 lb/in² or two-thirds of the 0·1% proof stress (whichever is the less). But small amounts of plastic deformation, quite impossible to avoid in practical fabrication, may be sufficient to cause such failure in some 18–8 steels (especially duplex alloys and those that transform especially readily when strained) with little or no applied stress. The data are insufficient at present to indicate if any, indeed, of the 18–8-type steels are free from this danger. Again, although heavily cold-worked material may be immune at stresses below half the 0·1% proof stress, such material could not be welded without leaving some regions in the particularly dangerous condition.

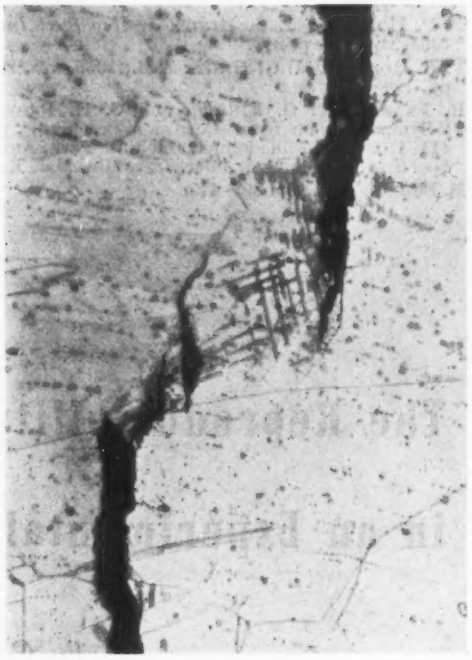


Fig. 7—Stress-corrosion crack and quasi-martensite remote from the point of fracture; same specimen as Fig. 6 × 750

The present results are in general harmony with the mechanism of stress-corrosion cracking that we have previously advanced.[2] It seems that both pre-straining and refrigeration increase the number of potential surface sites from which stress-corrosion cracks may be initiated, and thus, at high stresses particularly, decrease the necessary induction period during which bare metal becomes exposed to the electrolyte, and increase the number of cracks produced. The additional sites for crack initiation are probably at or near quasi-martensite plates in the surface; it may well be that the high local stresses associated with such plates are important in assisting the anodic process of crack initiation previously elaborated.[2] On the other hand, quasi-martensite in the bulk of the metal does not seem to play an important part in crack-propagation. It may be noted that many of the results of Edeleanu,[7] at first thought to support the view of the propagation of cracks along preferential paths of quasi-martensite, may be as well explained if quasi-martensite is important, as we believe, in crack *initiation* rather than in crack propagation.

Acknowledgments

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References

1. T. P. Hoar and J. G. Hines: *J. Iron Steel Inst.*, 1954, vol. 177, p. 248.
2. T. P. Hoar and J. G. Hines: *Ibid.*, 1955, vol. 182, pp. 124–143.
3. R. Franks, W. O. Binder, and C. H. Brown: "Symposium on Stress-Corrosion Cracking," pp. 411–420: 1945, Philadelphia and New York, Amer. Soc. Testing Mat. and Amer. Inst. Min. Met. Eng.
4. M. Scheil: *Ibid.*, pp. 395–410.
5. W. Tofaute and H. J. Rocha: *Tech. Met.*, 1950, Dec., p. 427.
6. H. J. Rocha: *Stahl u. Eisen*, 1942, vol. 62, pp. 1091–1094.
7. C. Edeleanu: *J. Iron Steel Inst.*, 1953, vol. 173, pp. 140–146.
8. J. T. Waber: "Theory of Stress-Corrosion Cracking of Mild Steel," p. 80: 1948, Pittsburgh, Corrosion Publishing Co.; and private communication, 1951.
9. T. Angel: *J. Iron Steel Inst.*, 1954, vol. 177, pp. 165–174.
10. F. H. Keating: Private communication, 1955.

The Reproducibility of Test Results in an Experimental Sinter Box

By C. Lang and J. M. Ridgion

SYNOPSIS

A study has been made of the variability of results obtained on the experimental sinter unit. The effect of changing from the normal to the segregated feed type box and of varying bed height has been statistically assessed. More reproducible results were obtained with the segregated feed box and with the deeper beds.

1284

Introduction

SMALL SINTER BOXES are frequently used to assess fuel requirements, air to sinter, time to sinter, etc., and the results obtained are used as design data for full-scale sinter plants.

Single test results are subject to errors and nothing has been published indicating the probable limits of error when making single or repeat tests.

Many duplicate and triplicate experiments have been made under controlled conditions on the 2-ft square sinter box at Warrenby in order to show the variation in the major parameters. The results obtained have been subjected to statistical analysis.

Materials Used

Ouenza fines screened at $-\frac{1}{2}$ in. were used, the size analysis being as follows :

Size, in.	$+\frac{1}{4}$	$-\frac{1}{4}+\frac{1}{8}$	$-\frac{1}{8}+\frac{1}{16}$	$-\frac{1}{16}+\frac{1}{32}$	$-\frac{1}{32}$
%	21·8	23·7	18·1	12·2	24·2

As a preliminary, a stockpile of return fines was made from Ouenza and graded in three size fractions : $-\frac{1}{2}+\frac{1}{4}$; $-\frac{1}{4}+\frac{1}{8}$; $-\frac{1}{8}$ in. These fractions were subsequently used in the standard proportions 22·2: 38·2: 39·6.

The coke used was normal breeze, rod-milled to $-\frac{1}{8}$ in.

Variables Examined

A sinter mix of standard proportions was used throughout. Each set of conditions was repeated seven times.

The first series were carried out with a 10-in. bed height using 16-in. w.g. initial suction. Half the tests were done in the ' normal ' sinter box and half with a segregated feed using the special box illustrated in Fig. 1. Each group was further subdivided; in half (series *A*) the ore was screened at $\frac{1}{4}$ in. and $\frac{1}{8}$ in. and remixed in the proportions 21·8% $+\frac{1}{4}$, 23·7% $-\frac{1}{4}+\frac{1}{8}$, 54·4% $-\frac{1}{8}$ to limit the possibility of segregation in the fine ore stock: in the other half (series *B*) ore was taken direct from stock with the same average size grading but with a possibility of variations between batches.

The remaining series were based on the ' normal '

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The views expressed are the authors' and are not necessarily endorsed by the Committee as a body.

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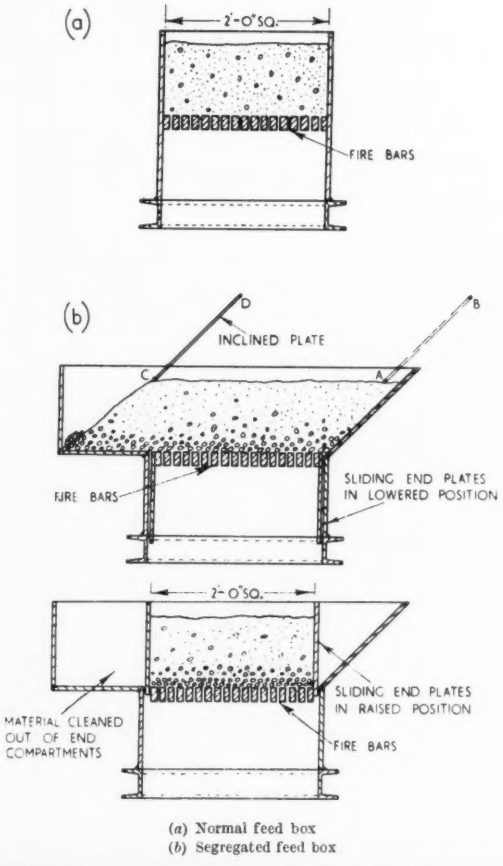
box with ore direct from stock but using bed heights of 8 in. and 6 in. In the latter tests the initial suctions were 13 and 9½ in. w.g. respectively to maintain the previous level of pressure drop per unit height.

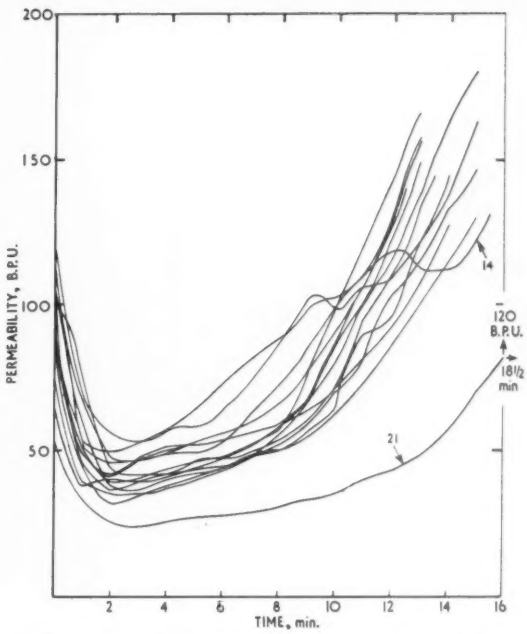
Mixing and Sintering

The sinter mix had previously been determined as being 59% ore, 25½% return fines, 4½% coke, and 11% moisture. The ore and return fines were weighed and hand-mixed on the floor; the correct moisture addition was made whilst mixing continued and finally the coke was added. Each mixing operation resulted in three complete turnovers of the mix pile. The raw mix was then loaded by shovel into the ' normal ' box (Fig. 1*a*). For filling the ' segregated feed ' box (Fig. 1*b*), the sliding end plates were lowered below grate level and an inclined plate supported in position *AB*. The mix was spread by shovel on to the inclined plate, this being slowly moved from right to left until it reached position *CD*. It will be seen that the effect is similar to that obtained by using a swinging spout feeding on to a fixed cut-off plate over a moving strand. With the box charged, the end plates were raised from ambush to give the standard sintering area of 2 ft × 2 ft. The edges of the end plates were then clayed up. The sinter mix was levelled at the correct height and the box and mix weighed.



(*a*) Normal feed box
(*b*) Segregated feed box

Fig. 1—Diagrammatic sketch of types of feed box used



Raw mix: 59% Ouenza, 25½% return fines, 4½% coke, 11% moisture
10-in. bed height. 16-in. w.g. initial suction

Fig. 2—Variation in bed permeability during sintering (normal feed box)

The sinter box was placed on the suction chamber, the airflow before ignition noted, and the sinter ignited for 1 min at constant airflow. After ignition, the suction was raised to the desired level and held at this until the increased bed permeability prevented it being maintained because of the limit of the fan.

Waste-gas temperature, airflow, and suction measurements were recorded every minute at the start and every half-minute towards the end of sintering. The time to sinter was taken as the time from start of ignition until the maximum waste gas temperature. After sintering was complete, the box was removed, the loss in weight noted, and the sinter cake tipped. The cake was broken down to approximately 3 in. maximum size and the sinter screened and the size fractions weighed. The sinter + ½ in. was crushed and a sample removed for a drop test.

RESULTS

The detailed results for the test series are given in Tables I–III. Table I gives the data obtained using the ' normal ' box with a 10-in. bed height, Table II gives the corresponding figures for the ' segregated ' box, whilst Table III is for the ' normal ' box with 8-in. and 6-in. bed heights.

A point of some interest which was observed related to the weight of raw material in the box, from which

Table I

RESULTS : NORMAL BOX (10-in. BED HEIGHT)

Test No.	Bulk Density, lb/ft³	Time to Sinter, min	Air Requirements, ft³ (S.T.P.)			Permeability, B.P.U.			Loss on Sintering, % of raw mix	Sinter Cake		Strength Index	Dust Index	Degree of Oxidation,
			Total Air Flow	per ton of raw mix	per ft² per min	Pre-ign.	Trough	Average		+ ½ in., %	− ½ in., %			
Series A														
2	109	13½	4739	29,160	88	103	41½	76	19	41	31½	65½	12	93·5
6	111	14½	4863	29,370	84	96	41	72	18	36½	29½	74	10	95·5
7	105	14	4380	28,000	78	112	36	66½	18	42½	32½	72	11	94·2
10	111	14	4503	27,170	80½	99	41	67	22½	37½	21½	73	10	93·5
12	104	12½	4868	31,470	97	118	53	82	19	49	29	—	—	95·1
14*	110	15½*	6806*	41,480*	110*	85*	50*	87½*	20	44½	33	68	11½	95·5
19	105	15	4780	30,900	79½	65	39	64	19½	44	36	68½	12½	95·5
Mean	108	14	4689	29,350	84½	99	42	71	19½	42	32	70	11	94·7
Series B														
20	105	13¼	4750	30,390	89½	105	46	78½	19	49½	25½	66½	12	—
21	105	18¼	4444	28,430	61	52½	24	48	19	47	31	61½	13	95·1
23	103	13	4191	27,370	80½	87½	36	68	19½	40	37	67	12½	94·4
24	104	13¾	4377	28,290	79½	93	31	67½	20	47½	32	71	11½	94·2
26	104	13	4739	30,660	91	—	45½	77½	18½	42	36½	73	10½	94·0
27	103	15	5208	34,000	87	72½	35	78	18½	40	38½	68½	11½	95·0
33	100	13¼	4637	30,910	87½	85½	39	77	17½	42½	39	68½	11	93·7
Mean	103	14	4621	30,000	82	82½	39	74	19	44	27½	68½	11½	94·4

* This test has been neglected owing to the abnormally high air figure
Raw Mix: 59% Ouenza, 25½ Return Fines, 4½% Coke, 11% Moisture. Normal Feed Box. 10-in. Bed Height. 16-in. w.g. Initial Suction

is derived bulk density and air requirements per ton. This is normally obtained by weighing the sinter box before and after filling, using a crane-suspended spring balance with scale divisions at intervals of 7 lb. All constituents of the mix were weighed before mixing and the weight of unused residue observed. It was found that the difference in the estimate of weight sintered could amount to as much as 14 lb (4% on a

Table II

RESULTS : SEGREGATED BOX

Test No.	Bulk Density, lb/ft³	Time to Sinter, min	Air Requirements, ft³ (S.T.P.)			Permeability, B.P.U.			Loss on Sintering, % of raw mix	Sinter Cake		Strength Index	Dust Index	Degree of Oxidation,
			Total Air Flow	per ton of raw mix	per ft² per min	Pre-ign.	Trough	Average		+ ½ in., %	− ½ in., %			
Series A														
9	105	11	5067	32,400	115	151	66	105½	17	52½	32½	64	11½	—
11	108	12¼	5202	32,320	106	153	59	93½	18½	46½	25	62	13	93·4
13	106	11¾	5257	33,300	112	145	67	102	21	51½	24	59½	12½	—
15	105	12	5050	32,320	105	137½	56	94	21	47½	23	65	11½	95·2
16	96½	10½	4703	32,700	112	145	66	99½	19½	39½	31½	63½	12	95·2
17	102	10½	4595	30,300	109½	125	62	97	18½	47	29	72	13	95·1
18	105	11	5091	32,570	115½	117½	68½	101½	20	41½	27½	63	12½	93·4
Mean	104	11	4995	32,270	111	139	63½	99	19	46½	27½	64	12½	94·5
Series B														
22	105	12	4663	29,840	97	125	51	85	21	41	29	66	12½	94·4
25	105	12	5167	33,060	107½	122½	56	99	18	48	23	72½	10	92·6
28	100	11	4665	31,360	106	126½	55½	92½	17	36	37½	66½	12½	94·3
29	103	11½	4897	31,960	106½	110	50	96	18½	37	37	67	12	92·7
30	102	11½	4453	29,400	97	92½	44	83½	19½	31	38	68	11	91·6
31	100	11¼	5125	34,310	114	132	65	107	22	46	29½	70	11	93·7
32	102	11	4603	30,370	104½	127½	58	96½	22½	42	34½	59	12	93·3
Mean	102	11½	4796	31,470	104½	119½	54	94	19½	40	32½	67	11½	93·2

Raw Mix: 59% Ouenza, 25½ Return Fines, 4½% Coke, 11% Moisture. Segregated Feed Box. 10-in. Bed Height. 16-in. w.g. Initial Suction

Table III—RESULTS: NORMAL BOX (8- AND 6-in. BED HEIGHT)

Series 2

8-in. Bed Height. 13-in. w.g. Initial Suction

Test No.	Bulk Density, lb ft³	Time to Sinter, min	Air Requirements, ft³ (S.T.P.)			Permeability, B.P.U.			Loss on Sintering, % of raw mix	Sinter Cake		Strength Index	Dust Index	Degree of Oxidation,
			Total Air Flow	per ton of raw mix	per ft² per min	Pre-ign.	Trough	Average		+ ½ in., %	− ½ in., %			
37	105	15	4023	32,190	67	48	28	51½	20	43	35½	72	11½	95·0
38	100	11	3704	31,180	84	60	28	70½	20	40½	36½	66	12	95·3
39	98	10	3663	31,430	92½	94	39	79	20	34½	39	63	12	92·8
42	106	11½	3785	29,900	82	75	38	71	19½	38½	32½	66	13	93·6
44	103½	10½	3345	27,080	79½	60	35	63	19	41	34	69	11½	94·5
46	102½	11¼	3804	21,150	84½	62½	34	73	19	47½	28½	65	12	93·8
47	103½	11½	3782	30,650	82	64	34	57½	16½	39	37	63	12	94·4
Mean	102½	11½		30,510	81½	66	33½	66½	19	40½	34½	66	12	94·2

Series 3

6-in. Bed Height. 9½-in. w.g. Initial Suction

34	101½	10½	2427	26,720	57½	55	27	44	17	16½	52	60½	14½	93·3
35	98	10¼	2477	29,860	63½	51	28	48½	18	31	46½	57	14	93·8
36	103	8¼	2788	30,240	84½	76	32	67½	20	34½	44½	55½	13½	93·7
40	96	7½	2490	28,960	83	85	41	68	19½	19	43½	59½	14½	94·6
41	100	9	2512	28,200	70	59	26	54	17⅞	31	40½	57½	13½	94·2
43	100	7¾	2787	31,290	90	85	35½	71	17½	35½	38	56	14	94·6
45	91	7	2192	26,950	78	69	37½	63	21	35½	33	56	12½	94·3
Mean	98½	8½		28,800	75	68½	32½	59½	18½	29	42½	57½	13½	94·0

Raw Mix: 59% Ouenza, 25½ Return Fines, 4½% Coke, 11% Moisture. Normal Feed Box.

Table IV
STATISTICAL ANALYSIS OF RESULTS

Feed	Segregated	Normal	Normal	Normal
Depth of bed, in.	10	10	8	6
Air per ton, ft³				
Mean	31,870	29,700	30,510	28,800
Standard deviation	1485	2035	1668	1678
Coefficient of variance (SD/M), %	4·7	6·9	5·5	5·8
Standard error of C of V, %	0·9	1·4	1·5	1·6
Total Airflow, ft³				
Mean	4895	4652	3729	2524
Standard deviation	271	269	204	209
Coefficient of variance (SD/M), %	5·5	5·8	5·5	8·3
Standard error of C of V, %	1·0	1·1	1·5	2·2
Average Permeability, B.P.U.				
Mean	96·5	71·0	66·5	59·5
Standard deviation	6·7	9·0	9·6	10·6
Coefficient of variance (SD/M), %	6·9	12·7	14·7	17·8
Standard error of C of V, %	1·3	2·5	3·9	4·7
Sintering Time, min				
Mean	11·4	14·1	11·5	8·5
Standard deviation	0·56	1·46	1·6	1·3
Coefficient of variance (SD/M), %	4·9	10·3	14·1	15·6
Standard error of C of V, %	0·9	2·0	3·7	4·2

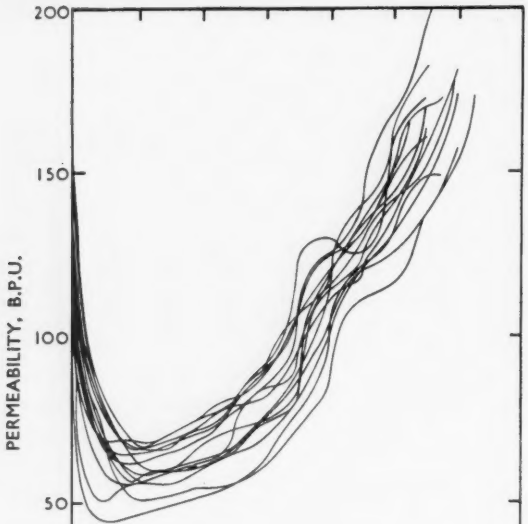
10-in. bed and proportionately more on the small bed height), the spring balance weights being lower in 80% of the instances. Spring balance weights have been used throughout in the tabulated results. Consideration is being given to improving weighing facilities for the future.

In considering the results in general, it is convenient to deal first with possible effects of the special precautions taken in series *A* to ensure more consistent size analysis of the ore. Statistical tests* were applied to assess the significance of differences in average values of parameters *A* and *B*. The differences were not significant, *t* reaching a value of 1·5 in one case only and being mostly less than 1·0. Test No. 14 was shown to be completely outside the general range of variation; it was therefore discarded.

As the hypothesis that series *A* and *B* were distinct had no experimental support, they were combined with each other and the differences between 'normal' and 'segregated' box results examined. Table IV gives the relevant statistics.

Taking as an example the mean air requirements per ton for the 10-in. beds, segregated and normal, it will be noted that the difference between the means is 2170, the significance of which is to be tested against the combined variance of the two series. This test gives $t = 3·2$, a result which would only arise by

* The statistic *t* referred to is the ratio of the difference in means to the standard error. Tables exist giving the probability that a given value of *t* may have arisen by chance.



Raw mix: 59% Ouenza, 25½% return fines, 4½% coke, 11% moisture
10-in. bed height. 16-in. w.g. initial suction

Fig. 3—Variation in bed permeability during sintering (segregated feed box)

chance once in a hundred, i.e. the difference is significant. In fact, all the parameters in Table IV show significant differences between the ' segregated ' and ' normal ' tests. On the other hand the size analysis of the products did not disclose any significant differences.

The coefficient of variance (standard deviation as a percentage of the mean), being based on a limited number of results from a potentially large population of tests, is only an estimate of the true value and has a standard error as shown in Table IV. Thus the first coefficient of variance (air/ton, segregated), is 4·7% with a standard error of 0·9% which means that there is a 95% chance that the true coefficient of variance lies within the range 3·8–5·6% (C. of V. ± S.E.). In general the segregated test results are less variable than those obtained with normal feed. These considerations also apply to the variations in permeability throughout the sintering period (*see* Figs. 2 and 3).

For the shallower beds, permeability and sintering time become more variable as the height decreases. It is also to be noted that the size analysis and strength tests show progressive deterioration as the bed is reduced in height to 6 in.

It is often useful in deducing air requirements per ton from a series of tests to make use of the formula:

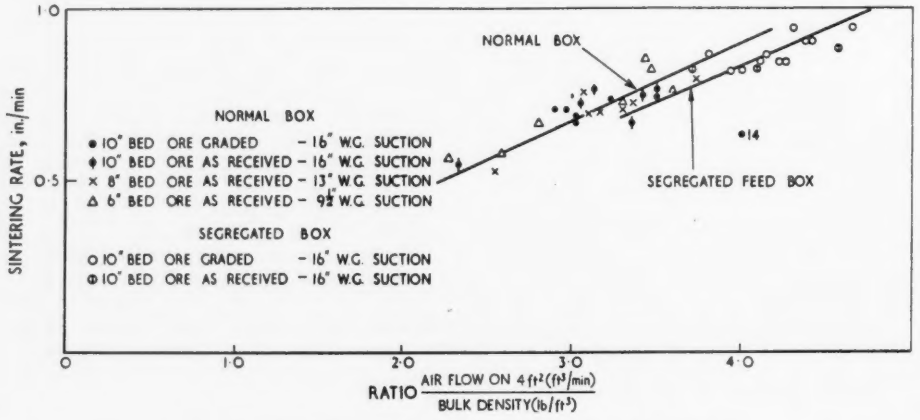
$$f = \frac{26900\ F}{A\ V\ B}$$

where f = sinter rate (in./min)
F = sintering airflow (ft³/min)
A = grate area (ft²)
V = air/ton of raw mix (ft³ at S.T.P.)
B = bulk density (lb/ft³)

by plotting f against F/B and deducing V from the slope of the resulting line. This has been done in Fig. 4 which shows two straight lines for ' normal ' and ' segregated ' data corresponding to 29,900 and 32,200 ft³/ton respectively. This difference, also observed in Table IV, is most probably due to increased leakage at the end-plates of the segregated feed box despite the precautions taken in claying up. All air/ton figures do of course include a certain amount of leakage at the edges of the sinter cake and through cracks.

PROBABLE ERRORS IN SINTER BOX TESTS

In carrying out tests on the sintering characteristics of various ores and mixes, it is necessary to vary a


SINTERING RATE, in./min
1·0
0·5
0
1·0
2·0
3·0
4·0
RATIO AIR FLOW ON 4 ft² (ft³/min) / BULK DENSITY (lb/ft³)
NORMAL BOX
SEGREGATED FEED BOX
•14
NORMAL BOX
• 10" BED ORE GRADED – 16" W.G. SUCTION
♦ 10" BED ORE AS RECEIVED – 16" W.G. SUCTION
× 8" BED ORE AS RECEIVED – 13" W.G. SUCTION
△ 6" BED ORE AS RECEIVED – 9½" W.G. SUCTION
SEGREGATED BOX
○ 10" BED ORE GRADED – 16" W.G. SUCTION
⊕ 10" BED ORE AS RECEIVED – 16" W.G. SUCTION

Raw mix: 59% Ouenza, 25½% return fines, 4½% coke, 11% moisture

Fig. 4—Relationship between air flow/bulk density rates and rate of sintering

number of factors such as proportions of fuel, moisture and return fines, and depth of bed. As a result, despite intelligent selection of the most useful combinations for study, a considerable number of different box tests are needed. This makes it impracticable to perform numerous repetitions of each experiment. A knowledge of the accuracy to be expected from averaging two, three, or four test results is therefore most desirable and the various statistics derived from the present work are most relevant to the problem.

It is not possible to lay down tolerances of general application; where small numbers of test data are in question, each case must be examined in detail. In a series of triplicate tests carried out at three levels of return fines, for example, the average values for sintering time are based on three results but the average air/ton figures may be derived from nine experiments if, as is probable, it can be shown that the entire series of results is in accord with a common air/ton value. A similar case arose in the present series where it was demonstrated that a total of 14 tests from series *A* and *B* could be combined to give common statistics.

If we take the present results of 14 tests we can deduce the probable errors which would have obtained in sets of 3 or 4 tests. Even here we have access to but 14 results from a very large number which might have been done. For simplicity it will be assumed that the mean values and standard deviations derived from the series constitute a sufficiently accurate guide to the corresponding statistics for the wider potential population of results. On this hypothesis it may be shown that if n tests are carried out, the difference between the mean thus obtained and the true mean may be expected to exceed $1{\cdot}96\frac{\sigma}{\sqrt{n}}$ (where σ is the standard deviation from Table IV) in only 1 case in 20.

As an example we may take the figure of air/ton from Table IV (segregated feed results) where $\sigma = 1485$. Then the following differences from the true mean value may be expected to arise on 5% of all occasions:

Number of Tests	Difference Term
1	2695
2	1907
3	1556
4	1345
5	1205
10	853
14	721

The appropriate number of tests to carry out is a compromise and must remain a matter of opinion but in general it appears that triplicate results are not inappropriate for normal work.

Under conditions similar to the present segregated feed series, triplicate tests would give a 20 to 1 chance of being within 6% of the true values of the characteristics set out in Table IV. For the ' normal ' series, sintering times would be liable to errors $2\frac{1}{2}$ times as great.

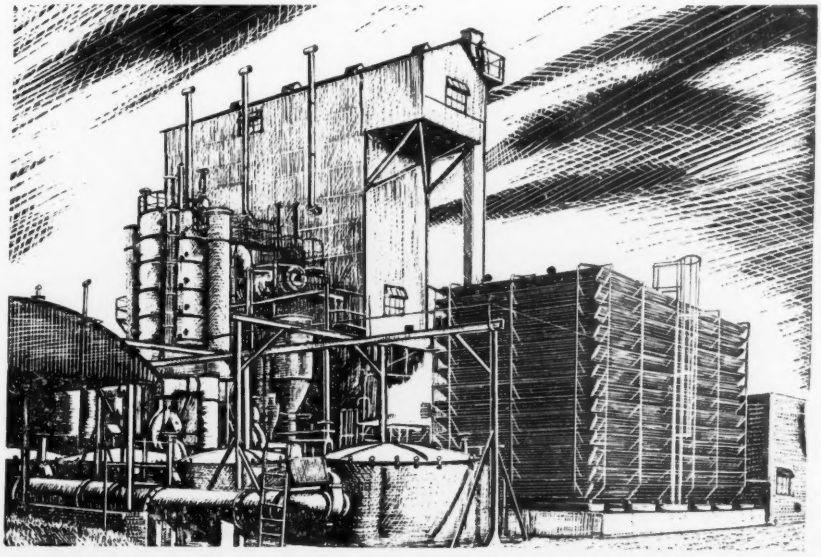
SUMMARY AND CONCLUSIONS

A large number of replicate sinter box tests has been carried out to assess the variability of the technique. It has been shown that the results using $-\frac{1}{2}$ in. ore are not unduly sensitive to the sampling variations in size analysis so that conventional methods of taking the ore sample are adequate.

Comparison of results using the segregated feed box with those obtained by the normal technique showed significant differences with a higher air/ton, higher permeability, and lower sintering time for the segregated box, conditions of constant suction obtaining in each case. Data from the segregated feed box were less variable than the others.

Tests with a smaller bed height showed rather more variability.

The results obtained from single tests are shown to be subject to appreciable error and this error is considerably reduced by averaging the results of triplicate tests.



Variation in Fatigue Properties Over Individual Casts of Steel

Part I—INVESTIGATION OF A CAST OF STEEL TO B.S. 970 SPECIFICATION En. 100

By E. Ineson, B.Sc., F.I.M., J. Clayton-Cave, and R. J. Taylor, B.Sc., F.S.S.

SYNOPSIS

An investigation is being made to establish whether or not the fatigue properties of the rolled products of commercial steel ingots vary significantly firstly within an individual ingot, and secondly from ingot to ingot in a given cast of steel. The present paper is concerned with a typical cast (bottom poured) of acid O.H. steel made to B.S. 970 specification En. 100. Five hundred test pieces, hardened and tempered to a nominal U.T.S. of 60–65 tons/in², were tested in fatigue according to a statistically designed experiment. Supplementary metallurgical information regarding composition variations, distribution of non-metallic inclusions, hardenability, and tensile properties was also accumulated.

It has been shown that the longitudinal fatigue properties are relatively uniform throughout this cast of steel. The only noticeable variation was at the top of an ingot which showed slightly better properties but is considered to be unimportant from a practical point of view. The dispersion of non-metallic inclusions, of the types and sizes usually observed in this class of steels, was relatively uniform throughout the cast; but examination of the fracture surfaces showed no evidence that any inclusions were responsible for the initiation of the fatigue failures. 1311

THE METALLURGICAL STRUCTURE of commercial steel ingots has been fairly thoroughly investigated over the past 25 years and a relatively complete knowledge now exists concerning their somewhat heterogeneous nature.[1] Rather less is known, however, about the influence of this heterogeneous ingot structure on the mechanical properties of rolled and forged products of an ingot, though some effort has been made to relate the two.

The numbers, types, and distribution of non-metallic inclusions are closely related to the cast structure of an ingot and particular attention has been paid to a study of these in this work. Many methods have been proposed for assessing the non-metallic inclusion content of steels; and several methods of inclusion counting have been adopted and standardized by various bodies as acceptance tests for steels. This somewhat arbitrary action has partly arisen from speculation on the supposed effects of inclusions on mechanical properties and must inevitably have led to undue caution in selecting steel for particular purposes.

Fatigue tests have proved to be most sensitive to those variations in quality of steels which are important in practice. In recent years, Frith[2] has carried out a comprehensive programme of fatigue tests aimed at establishing more definitely the influence of various metallurgical factors, including non-metallic inclusions, on the behaviour of steels in service. One result of Frith's work was that only certain types of inclusion, particularly non-deformable spherical silicates, were found to be harmful; and even these only appeared to exert a serious effect at strengths greater than 100 tons/in² U.T.S. Much of Frith's work was carried out on material selected from one part of one ingot from any given cast, and there still remained the questions of whether a variation in properties could be expected from bars rolled from different positions of the same ingot and also whether different ingots from the same cast would have similar properties. Frith was able to explore these points in a limited way, from which he concluded that there was reasonable agreement between fatigue results obtained from different ingots of the same cast, but that there was a variation in fatigue properties for bars rolled from different positions of the same ingot. However, because of the limited scope of these experiments, the results were inconclusive, and it was suggested that a full exploration of these possible variations should be undertaken.

This problem was undertaken by the B.I.S.R.A. Fatigue Testing Laboratory and several typical casts of steel were made available, from which representative ingots were selected. An overall plan was prepared whereby the behaviour of the steels should be explored at various levels of tensile strength, and, in view of the well-known scatter of fatigue results, a statistical approach was adopted. An initial experiment had previously been carried out to assess the variability of the batch of fatigue testing machines to be used in the investigation.[3]

One of the steels chosen was an acid O.H. cast made to B.S. 970 specification En. 100, and the present paper is concerned with the results obtained for this particular steel, heat-treated to a nominal U.T.S. of 60–65 tons/in².

METALLURGICAL DETAILS OF MATERIAL

Supply of Material

The material used for this part of the investigation was obtained from three ingots taken from a commercial cast of acid O.H. steel to B.S. 970 specification En. 100. The heat of approximately 45 tons was cast by bottom running into 33 ingots, consisting of five groups of six ingots, followed by a two-way

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Mr. E. Ineson is Laboratory Head and Mr. Clayton-Cave an investigator in the Metallurgy (General) Division. Mr. Taylor is in the Operational Research Section of the Association.

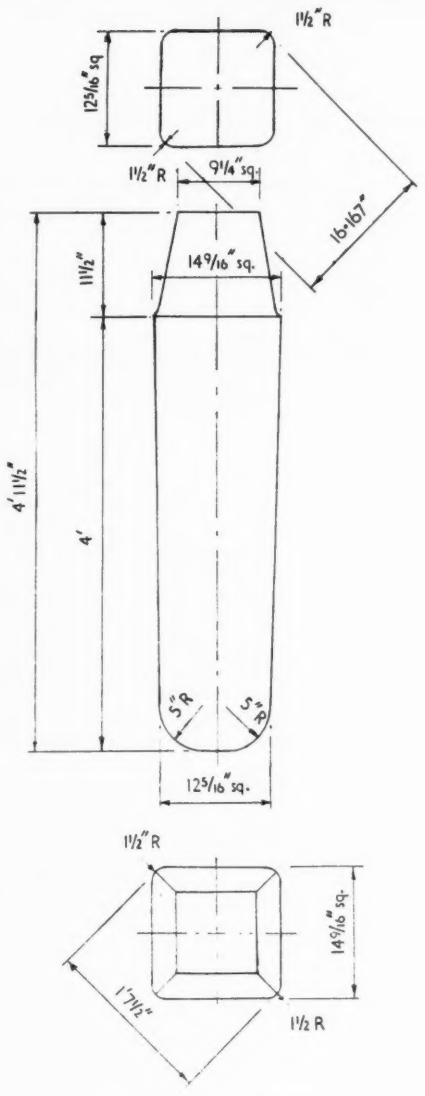


Fig. 1—Details of ingot

and a single ingot. Figure 1 shows the dimensions of an ingot.

The choice of ingots and ingot positions for investigation in relation to the whole cast is shown in diagrammatic form in Fig. 2. This figure also illustrates the stages of rolling from the ingots to $\frac{7}{8}$-in. dia. bars and the method of identification.

The ingots were hot-rolled, the top end entering first, in a 27-in. 2-high reversing cogging mill to approximately 8 in. × 6 in. A $12\frac{1}{2}\%$ discard was cut from the head and rolling then continued to 5-in. square. At this stage the rolling reduction given to the top of the ingot was approximately 88%, against a reduction of approximately 83% to the bottom of the ingot. After cutting a 2% bottom discard, the product of each ingot was cut into five equal pieces. The billets were placed in a slow cooling pit after rolling.

Five of the 5-in. square billets were selected, three representing the top, middle, and bottom portions of ingot *1* and the other two representing the middle of ingots *15* and *31*. These billets were reheated and rolled to 3-in. Gothic and subsequently re-heated again and rolled to $\frac{7}{8}$-in. dia. bars. This re-rolling involved a further rolling reduction of approximately $98\frac{1}{2}\%$ from the 5-in. square billet stage.

At all stages of rolling between ingot and $\frac{7}{8}$-in. bar, examination was made for defects. Great care was taken to ensure that the identity of bars with respect to the original ingot and ingot position was known exactly.

Examination of Structure and Mechanical Properties of the Material

Analysis and Segregation—The cast analysis together with check analyses for the five ingot positions are given in Table I. These results show that the steel is well within specification and there does not appear to be any significant difference in composition between any of the ingot positions. In addition, spectrographic tests were made for other elements and the results were identical for each ingot position (Cu, 0·1%; Va, 0·01%; Sn, 0·02%; and Co and Al both less than 0·02%).

However, it is known that certain elements tend to segregate in particular regions of an ingot and to investigate this possibility, sections cut from 5-in. billets were sulphur-printed. The sections used for this were immediately adjacent to and representative of the original ingot positions. The sulphur prints

Table I

CHECK ANALYSIS ON SAMPLES FROM THE FIVE INGOT POSITIONS

Composition, wt-%	Specification B.S. 970 En. 100	Cast Analysis	Ingot *1*			Ingot *15* Middle	Ingot *31* Middle
			Top	Middle	Bottom		
Carbon	0·35–0·45	0·38	0·37	0·35	0·36	0·37	0·38
Silicon	0·50 max.	0·25	0·24	0·24	0·24	0·25	0·23
Manganese	1·20–1·50	1·44	1·48	1·48	1·47	1·50	1·48
Sulphur	0·50 max.	0·036	0·039	0·038	0·039	0·040	0·039
Phosphorus	0·05 max.	0·025	0·037	0·035	0·034	0·035	0·036
Chromium	0·30–0·60	0·42	0·42	0·42	0·43	0·42	0·42
Nickel	0·50–1·00	0·57	0·58	0·58	0·58	0·58	0·57
Molybdenum	0·15–0·25	0·15	0·17	0·18	0·17	0·18	0·18

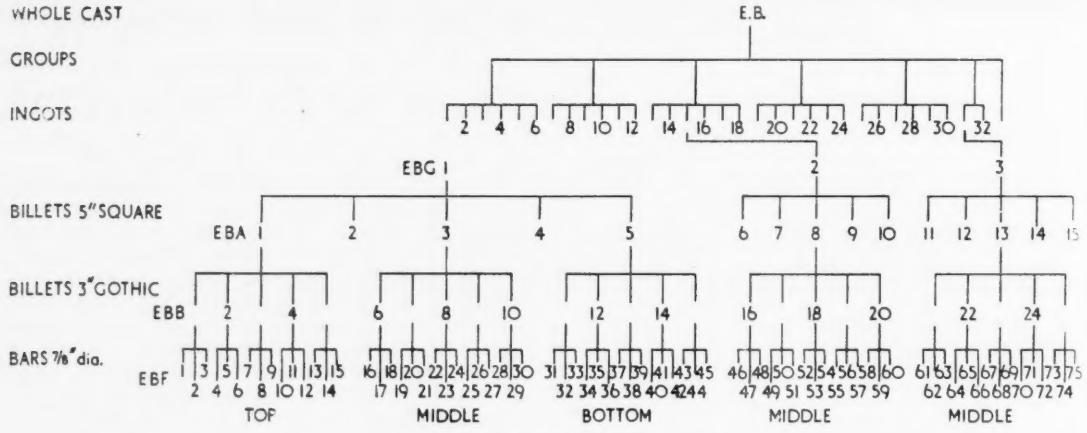


Fig. 2—Details of cast

showed a marked central square for the bottom and middle portions of the ingots, but the section representing the top of ingot *1* showed no indication of a central square.

The diameter of the critical section of the test pieces used in this research was 0·3 in. and as there was evidence of sulphur segregation, the centres of the $\frac{7}{8}$-in. dia. bars were examined for composition variations. Samples were drilled (0·3-in. dia. drill) from the centre of each bar used in the experiment. The results of the analyses of these samples are shown in Table II.

These results, whilst conforming to the steel specification, indicate a slight increase in the carbon, sulphur, and phosphorus contents towards the top of ingot *1*. The carbon content for the middle portions of ingots *15* and *31* is also slightly higher than the corresponding value for the middle portion of ingot *1*.

Response to Hardening—Conventional Jominy End-Quench tests were carried out on samples from each of the five ingot positions. In view of the fact that only $\frac{7}{8}$-in. dia. bars were available, it was not possible to use standard test pieces for this purpose. A sub-standard diameter of $\frac{3}{4}$ in. was therefore adopted. The curves obtained showed no marked difference and were in agreement with those determined by Allsop and Steven[4] for this class of steel.

Table II

ANALYSES OF SAMPLES FROM THE CENTRE OF $\frac{7}{8}$-in. DIAMETER BARS REPRESENTING THE FIVE INGOT POSITIONS

(Each entry is averaged from analyses of ten bars)

	Ingot *1*			Ingot *15*	Ingot *31*
Composition, wt-%	**Bars 4–13 Top**	**Bars 19–28 Middle**	**Bars 34–43 Bottom**	**Bars 49–58 Middle**	**Bars 64–73 Middle**
Carbon	0·39	0·35	0·34	0·38	0·38
Silicon	0·24	0·23	0·23	0·23	0·23
Manganese	1·45	1·42	1·42	1·46	1·41
Sulphur	0·046	0·039	0·039	0·041	0·040
Phosphorus	0·038	0·033	0·031	0·033	0·033
Chromium	0·39	0·39	0·39	0·41	0·41
Nickel	0·62	0·62	0·63	0·62	0·61
Molybdenum	0·18	0·18	0·18	0·18	0·17

However, the information provided by the end-quench curves was not considered to be a sufficient guide to the actual hardness which fatigue test pieces (at 0·3 in. dia.) would attain after a given heat-treatment, particularly in view of the presence of a marked central square of varying size exhibited by the sulphur prints from the different ingot positions. The authors are indebted to Mr. H. Allsop of Brown Bayley Steels for assistance at this stage in carrying out extra tests to provide information on the hardness variations across the $\frac{7}{8}$-in. dia. bar after various heat-treatments. The tests were performed on thin discs cut from the $\frac{7}{8}$-in. dia. bars, Nos. *8*, *23* and *38* (*see* Fig. 2) representing the top, middle and bottom of ingot *1*. The heat-treatments given and the results of hardness explorations across the sections are indicated in Fig. 3. It is apparent from these results that the centre of bars *23* and *38* (representing the middle and bottom of ingot) tends to be low in hardness, whereas the hardness of bar *8* (top of ingot) is somewhat higher and does not differ appreciably across the section. The relationship between the hardness traverses and the presence of a central square is clearly indicated if Fig. 3 is compared with Fig. 4 which shows the macrostructure of the three discs after isothermal treatment. The examination was completed in the B.I.S.R.A. laboratory by examining discs cut from bars representing the middle portions of ingots *15* and *31*, and the hardness values obtained after the quenching and tempering treatment are also shown in Fig. 3. It is significant to note that if a diameter of 0·3 in. is considered, the hardness is relatively constant for all ingot positions with exception of the top of ingot *1* which shows slightly high values.

Grain Size—The austenitic grain size of samples representing the different ingot and cast positions being studied was measured and found to be A.S.T.M. 7. However, there was a wide variation in grain sizes within any one sample, the limits being A.S.T.M. 5 and A.S.T.M. 8. No difference existed between the samples from the various ingot positions.

Non-metallic Inclusions—The inclusion content of material representing the five ingot positions was

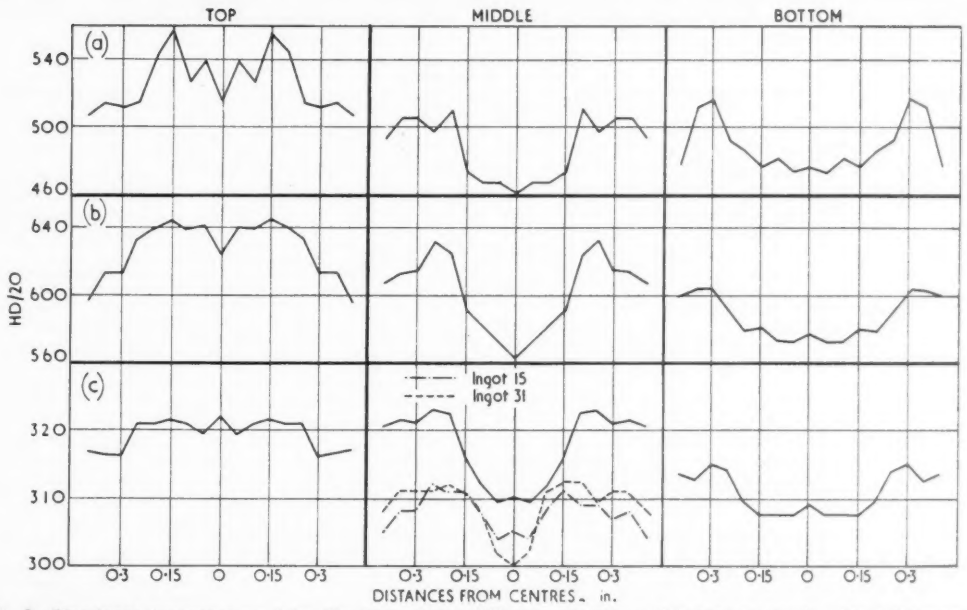


Fig. 3—Hardness traverses on $\frac{7}{8}$-in. dia. bars. from different positions of ingots (average of two traverses)

determined by a modified method of inclusion counting devised in the laboratory. Samples 0·5 in. × 0·3 in. were examined at a magnification of × 360 diameters (equivalent to an actual field of view of 0·37 mm dia.). The surface examined was a longitudinal section, 0·5-in. long cut along a diameter of a 0·3-in. dia. bar, turned from the original $\frac{7}{8}$-in. dia. stock. Sixteen fields were surveyed, chosen in a systematic manner to eliminate any personal element in selection. Three samples were examined for each ingot position, i.e. 48 fields of view.

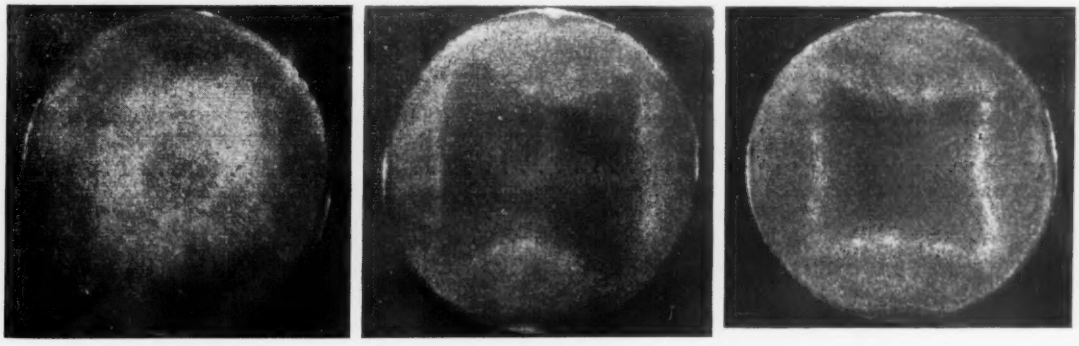
In determining the inclusion counts, the inclusions in each field of view were identified and each type classified into various sizes depending on their widths. The length of the longest inclusion observed for each type was also recorded. The counts obtained are shown in Table III.

In expressing the final results of the counts, the number of inclusions found in each size range, for the various types, is given as an aggregate together with the length of the longest inclusion observed. The values quoted are for total number of inclusions observed in 48 fields or in 4·6 mm² of the sample.

The majority of inclusions were of the manganese sulphide type and some of these were associated with silicate inclusions. There tend to be more silicates towards the top of ingot *1* and more oxides towards the bottom of the ingot.

Tensile Properties

A tensile blank was selected from the same relative position in each of the 50 separate $\frac{7}{8}$-in. dia. bars used in the investigation. The heat-treatment of these blanks was identical to that used in the preparation of the fatigue test pieces (oil-quenched from 850° C followed by tempering at 625° C). It was not possible to heat-treat a batch of 50 blanks together, but the 30 blanks representing ingot *1* were treated together and the remaining 20 blanks, representing the middle portions of ingots *15* and *31*, were treated as a second



(*a*) Top **(*b*) Middle** **(*c*) Bottom**

Fig. 4—Macrophotographs of $\frac{7}{8}$-in. dia. bars from different postions of ingot × 2

Table III— INCLUSION COUNTS FOR EACH INGOT POSITION

Position	Type of Inclusion	Total for range of sizes of widths × 0·0035 mm					Longest Inclusion Observed × 0·0035 mm	General Remarks
		0–1	1–2	2–4	4–8	8–16		
Ingot *1* Top	Aluminium oxide	5	3	—	—	—	3·0	***Aluminium Oxide*** Found usually in stringers in isolated patches
	Silicate	40	4	—	—	1	8·0	
	Manganese Sulphide	1425	1	—	—	—	20·0	
	Other Oxides	7	4	—	—	—	5·0	
Ingot *1* Middle	Aluminium Oxide	2	—	—	—	—	3·0	***Silicates*** Often associated with MnS. Two main types observed: (1) hard slightly deformable, (2) deformable varieties
	Silicate	48	2	1	1	—	7·0	
	Manganese Sulphide	1298	—	—	—	—	38·0	
	Other Oxides	10	—	—	—	—	3·0	
Ingot *1* Bottom	Aluminium Oxide	21	—	—	—	—	3·0	***Manganese Sulphide*** Generally evenly distributed. Often assoc. with silicates
	Silicate	23	—	2	—	—	4·0	
	Manganese Sulphide	1595	—	—	—	—	27·0	
	Other Oxides	34	10	—	—	—	4·0	
Ingot *15* Middle	Aluminium Oxide	1	—	—	—	—	3·0	***Other Oxides*** Usually found in isolated patches. Sometimes assoc. with other types
	Silicate	13	1	—	—	—	14·0	
	Manganese Sulphide	1774	—	—	—	—	19·0	
	Other Oxides	1	—	—	—	—	3·0	
Ingot *31* Middle	Aluminium Oxide	2	—	—	—	—	3·0	
	Silicate	7	—	—	—	—	4·0	
	Manganese Sulphide	1777	—	—	—	—	19·0	
	Other Oxides	—	—	—	—	—	—	

The range of sizes and the size of the longest inclusion indicated above are for a magnification of × 360 (equivalent to a field of view of 0·35 mm dia.) and for an area of approximately 4·6 mm².

batch. Tensile test pieces of 0·564 in. dia. were prepared and tensile tests carried out in conformity with B.S.18. Table IV lists these results.

There is no indication of differences between results from the middle portion of ingots *1*, *15*, and *31* but the top of ingot *1* shows an increase in tensile strength. These inferences are confirmed by analysis of variance (for U.T.S.)—*see* Table V.

DESIGN OF FATIGUE EXPERIMENT

Planning

The primary aim of the experiment was to compare the fatigue properties of material chosen from five different ingot positions within a cast of steel. It was essential that all other factors, which might influence the test results, be eliminated or at any rate balanced between the ingot positions. The use of more than one testing machine, choice of stress levels, variations along a bar, and variations in batch heat treatment are possible factors which can bias test results.

The experimental plan used in the present investigation is illustrated, in part, for one ingot position in Table VI.

In this arrangement, it can be seen that one and only one test piece from each bar is tested at each different stress level and in each of the ten machines. Further, the first test piece from each bar is tested

Table IV

TENSILE TESTS ON PIECES REPRESENTING THE 5 INGOT POSITIONS

(Each entry is averaged over ten tests)

Position in ingot	Yield strength, tons/in²	U.T.S., tons/in²	Elongation on $4\sqrt{A}$, %	Reduction in area, %
Ingot *1*:				
top	57·4	63·9	22	54
middle	56·5	62·3	22	54
bottom	55·7	62·1	23	55
Ingot *15*:				
middle	56·6	62·7	23	57
Ingot *31*:				
middle	56·3	62·7	22	56

Table V

ANALYSIS OF VARIANCE: TENSILE TESTS (U.T.S.)

Source of Variation	Degrees of Freedom	Mean Square	Test Ratio
Between ingots *1*, *15* and *31*	2	0·0544	0·44 Non significant
Between top, middle and bottom of Ingot *1*	2	10·7110	86·8 Highly significant
Residual	45	0·1234	—
Total	49	—	—

Table VI
PLAN OF EXPERIMENT

Stress Level	Machine Number 1	2	3	5	6	7	8	10	11	12
36·25	3*a**	4b	5c	6*d*	7*e*	8*f*	9*g*	10*h*	11*i*	12*j*
36·00	4*a*	5b	6c	7*d*	8*e*	9*f*	10*g*	11*h*	12*i*	3*j*
34·00	12*a*	3b	4c	5*d*	6*e*	7*f*	8*g*	9*h*	10*i*	11*j*

* The numbers shown in the cells represent ten consecutive bar numbers and the letters represent test pieces cut in consecutive order along each bar

in machine number one, the second test piece in the second machine and so on, the tenth consecutive piece being tested in machine number 12.

Repeating this programme for each of the five ingot positions permits a comparison of the fatigue properties of each, completely independent of machines and stress levels.

A total of 500 tests were involved in the complete investigation and slight changes in the conditions of the tests were conceivable during the testing period. To avoid a time bias, it was arranged to test in stress level order; that is, bars from each ingot position were tested more or less simultaneously, making any differences, due to the time factor, indistinguishable from those due to a stress factor.

Choice of Stress Levels

Conventional S/N determinations were made using material chosen from each of the five ingot positions and eight of the ten stress levels were decided on this basis (covering the range from $\pm$ 34·50 to $\pm$ 36·25 tons/in² by intervals of $\pm$ 0·25 tons/in²). The remaining two stress levels were reserved to complete the stress band. Not all test pieces remained unbroken at $\pm$ 34·50 tons/in², and so the remaining stress levels were allocated to $\pm$ 34·25 and $\pm$ 34·00 tons/in². Every test in which the test piece remained unbroken was stopped after 30×10^6 cycles were completed.

Heat-treatment of Test Bars

The furnace used for heat-treatment had a limited capacity and it was necessary to arrange for treatment in batches. The furnace could handle batches of about 30 test pieces at one time. Thus it is decided that the batching should be in the order indicated in the vertical columns of Table VI, i.e. all test pieces identified '*a*' should be in one batch, those identified as '*b*' in another, and so on. Twenty different furnace runs were involved, the first ten dealing with ingot *1* and the remaining ten dealing with ingots *15* and *31*. The heat-treatment of each batch consisted of oil-quenching from 850° C followed by tempering at 625° C. All heat-treatment was carried out on the $\frac{7}{8}$-in. dia. bar, i.e. prior to any machining.

As a check on the uniformity of the batch heat treatments, a tensile test piece cut from a common bar of material was included in each batch. In addition every heat-treated piece was checked for hardness on a Brinell hardness tester before machining and afterwards checked on a Vickers hardness tester. These tests showed that consistency of heat-treatment had been achieved throughout the experiment.

Representative pieces of $\frac{7}{8}$-in. dia. bar were also included in each heat-treatment batch and these were examined microscopically. In every case the as-quenched condition had a structure consisting largely of martensite near the surface which then changed to a mixture of bainite and martensite at the centre. In the tempered condition the structure was typical of this type of steel.

Table VII
FATIGUE PARAMETERS OF INGOTS *1*, *15* AND *31*

Position in Ingot	Fatigue Limit 95% ± tons/in²	Fatigue Limit 50% ± tons/in²	Fatigue ratio F.L. (95%): U.T.S.
Ingot *1*:			
top	34·3 (±0·5)	35·5 (±0·3)	0·537
middle	32·9 (±1·0)	34·1 (±0·4)	0·528
bottom	32·5 (±1·6)	33·9 (±0·7)	0·524
Ingot *5*:			
middle	32·5 (±1·4)	33·9 (±0·6)	0·518
Ingot *31*:			
middle	33·0 (±0·9)	34·1 (±0·3)	0·526

N.B.—The accuracy of each estimate of fatigue limit is shown by the figures in parentheses. These figures ('*t*' × standard error) define a range in which the true fatigue limit will be expected to lie with 95% confidence.

Table VIII
ANALYSIS OF VARIANCE: Logarithm of Number of Cycles to Failure

Source of Variation	Five Ingot Positions: Degrees of Freedom	Mean Square	Test Ratio	Four Ingot Positions (not top Ingot *1*): Degrees of Freedom	Mean Square	Test Ratio
Between ingot positions	4	0·1052	4·0†	3	0·0545	0·9*
Between machines	9	0·0261	1·0*	9	0·0200	0·3*
Residual	36	0·0265	..	27	0·0595	..
Total	49	—	—	39	—	—

* Non-significant † 1% significance level

Fatigue Testing Machines and Test Pieces

The testing machines used in the investigation were of the N.P.L. two-point loading, rotating beam type, described elsewhere.[5] The test pieces were such that the un-notched critical section is a uniformly, or nearly uniformly, loaded rotating cylinder of 0·3 in. dia. The actual design of the test piece, identified as '*F*,' is given in Ref. 3, and the methods adopted for machining and preparing the test pieces are identical to those described in Ref. 3.

Results of Fatigue Experiment

Each fatigue fracture was examined under a stereoscopic microscope (× 100). In no case was there any evidence that an inclusion initiated the failure. The characteristic feature of all fractures was a highly polished crescent-shaped area extending about halfway around the circumference and about one-third into the centre. Fatigue cracks appear to have started at or near the surface and propagated comparatively slowly over the crescent-shaped area. Then followed a period of more rapid propagation

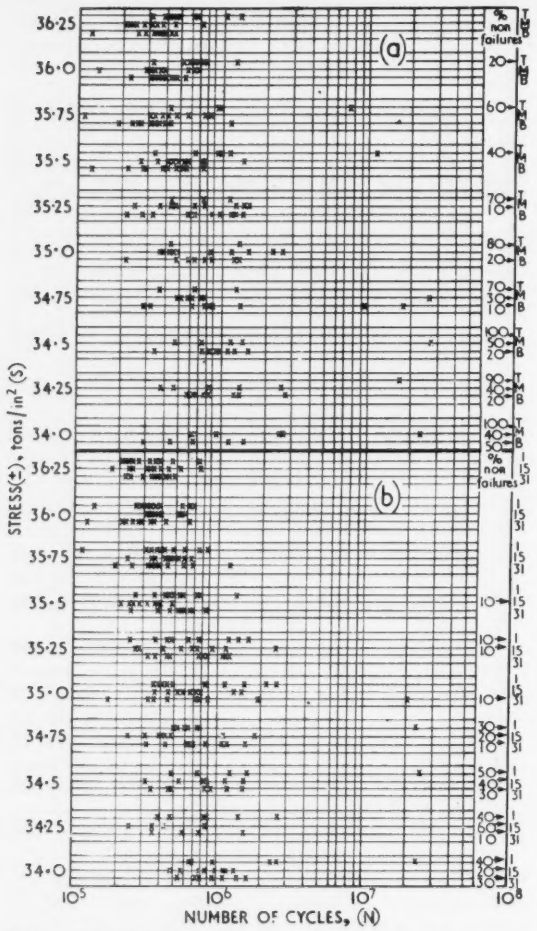


Fig. 5—Fatigue test results. (*a*) Ingot *1*, (*b*) Middle position of ingots *1*, *15*, and *31* (criterion for non-failures 30 + 10⁶ cycles)

over about the middle third of the fracture face, followed by the final failure with a fibrous fracture.

The results of the experiment are shown in Fig. 5. Each ingot position yields ten breaks at one stress level at least, but only the top of ingot *1* yields no breaks at the lowest stress level. Another feature of the results is the high degree of scatter. The mean life of test pieces breaking at a given stress level is sometimes less than the mean life observed at higher stress levels. This is true of every ingot position although it is not so pronounced for the top of ingot *1*. Figure 5 indicates that the results obtained from the top of ingot *1* differ from the results obtained from the other ingot positions. This inference is emphasized if the proportion of unbroken tests is considered.

However, to compare the fatigue properties of the ingot positions, it is necessary to describe these properties in a quantitative manner. This has been attempted by defining the parameters:

(i) The fatigue limit (95%)—that stress level at which 95% of tests are expected to exceed 30×10^6 cycles.

(ii) The fatigue limit (50%)—that stress level at which 50% of tests are expected to exceed 30×10^6 cycles.

These parameters are similar to the ' fatigue limit ' used in conventional fatigue tests. The advantages claimed for the percentage fatigue limit are that firstly, it may be determined analytically and is independent of subjective interpretation on the part of the investigator, and secondly, an estimate of its reliability can be made.

The relation between the percentage of tests exceeding 30×10^6 cycles and the test stress level is unknown. But analysis of results suggests that the probit transformation[6]

$$p_i = \int_{x_i+5}^{\infty} \frac{1}{\sqrt{2\pi}} l - \tfrac{1}{2}x^2 \, dx$$

where p_i is the proportion of non breaks at the stress level i

defines a variable (xi) which is linearly related to logarithm of stress (log i). From this relationship the fatigue limit and its standard error were estimated for each ingot position and the results are shown in Table VII.

The difference between the fatigue limits for the five ingot positions were tested for significance. The top portion of ingot *1* was found to differ significantly from the remainder of the ingot, but no significant difference is detectable between the bottom and middle of ingot *1*, nor between the middle portions of the three separate ingots. Table VII also shows that the fatigue and tensile properties are closely related at each ingot position.

A more sensitive statistical test was applied to the results (expressed as logarithm of number of cycles to failure, log N) obtained at stress level ± 36·25 tons/in.² Each ingot position yielded ten broken test pieces at this stress level and the total variance of the results was divided into three components as shown in Table VIII. The mean of log life for each ingot position is shown in Table IX.

Both Tables VIII and IX confirm that the top of ingot *1* differs significantly from the remaining four ingot positions although these four positions themselves have comparable fatigue properties. It is to be noted that there is no evidence that machine differences are significant in this investigation.

CONCLUSIONS

(1) The fatigue properties of this cast of En.100 steel appear to be relatively uniform throughout. Only three ingots out of a total of 33 in the cast were studied, but these are considered to be sufficiently representative of the cast.

Table IX

FATIGUE STATISTICS FOR LOGARITHM OF NUMBER OF CYCLES TO FAILURE

Stress Level ±36·25 tons/in²

Position in Ingot	Mean	Variance
Ingot *1*: top	5·74	0·0394
middle	5·51	0·0272
bottom	5·49	0·0251
Ingot *15*: middle	5·53	0·0297
Ingot *31*: middle	5·54	0·0107

(2) Small statistically significant variations within an ingot have been found, but these are not thought to be of any practical importance. The fatigue limit (95%) of the material from the top portion of ingot *1* is $\pm 34 \cdot 3$ tons/in^2 compared with $\pm 32 \cdot 9$ and $\pm 32 \cdot 5$ tons/in^2 for material from the middle and bottom portions of the same ingot. This difference in fatigue limit is closely linked with variations in hardness and tensile properties.

(3) The properties of middle portions of each of the three ingots chosen were similar in every way.

(4) The presence of a so-called ' low hardenability centre ' has been plainly indicated in the one whole ingot investigated. This central square has been shown to decrease in cross-sectional area from the bottom to the top of the ingot. This effect combined with the small but significant increase in carbon, sulphur, and phosphorus contents at the centre of the top portion of the ingot, would be sufficient to give rise to slightly greater hardness in heat-treatment, and thus to a large extent explain the increase in fatigue limit observed.

(5) The distribution of non-metallic inclusions is fairly uniform and there is no evidence that they have any influence on the longitudinal fatigue strength of this particular steel in the condition investigated.

Acknowledgments

The authors wish to thank the Chairman, Dr. H. H. Burton and past and present members of the Fatigue and Inclusion Committee for helpful and interesting discussion on this work. They are also grateful to Mr. H. Allsop for help and advice in the treatment of this steel and for carrying out supporting tests. The whole of the fatigue research is under the general supervision of Dr. M. L. Becker (Head of the Metallurgy Division of B.I.S.R.A.) whose helpful advice in the course of the investigation is greatly appreciated. Thanks are also due to Mr. T. R. Allmand for the help with the experimental work, particularly in connection with the assessment of inclusions.

References

1. Committee on the Heterogeneity of Steel Ingots: *J. Iron Steel Inst.*, 1926, vol. 113, pp. 39–176; *Ibid.*, 1928, vol. 117, pp. 401–571; *Ibid.*, 1929, vol. 119, pp. 305–389; *Ibid.*, Spec. Rep. No. 2, 1932, p. 267; Spec. Rep. No. 4, 1933, p. 79; Spec. Rep. No. 9, 1935, p. 236; Spec. Rep. No. 9A, 1936, p. 70 (Discussion); Spec. Rep. No. 16, 1937, p. 238; Spec. Rep. No. 25, 1939, p. 650.
2. P. H. Frith: Iron Steel Inst., Spec. Rep. No. 50, 1954, p. 128.
3. J. Clayton-Cave, R. J. Taylor, and E. Ineson: *J. Iron Steel Inst.*, 1955, vol. 180, pp. 161–169.
4. H. Allsop and W. Steven: Iron Steel Inst., Spec. Rep. No. 36, 1946, p. 215.
5. C. E. Phillips: Aeronautical Research Committee, 1948, Paper No. 7128.
6. D. J. Finney: Probit Analysis, 1952, Cambridge.

The Aluminium Reduction Method for the Determination of Oxygen in Steel

USED IN THE LABORATORIES OF THE STEEL COMPANY OF WALES LTD. (NEWPORT DIVISION)

By J. E. Wells, B.Sc., F.R.I.C., A.Met.

Introduction

THE ESTIMATION of oxygen in steel by conversion of the oxides present to alumina, followed by acid extraction and estimation of the alumina, is not new. Herty and his co-workers,[1] Swinden and Stevenson,[2] Speight,[3] and other workers have used this principle for the estimation of oxygen in liquid steel. In these methods a sample of liquid steel, taken in various ways, is killed with excess of aluminium, and the alumina formed is subsequently recovered by acid extraction and estimated.

Paper SM/C/8/56 of the Physical Chemistry of Steelmaking Committee of the Steelmaking Division of the British Iron and Steel Research Association, received on 3rd May, 1956. The views expressed are the author's and are not necessarily endorsed by the Committee as a body.

Mr. Wells is with the Steel Company of Wales Ltd. (Newport Division).

SYNOPSIS

A description is given of the procedure adopted for the determination of oxygen in steel by the aluminium reduction method operated *in vacuo*.

Typical results are presented and compared with results obtained by the vacuum-fusion method. In general, agreement between the two methods is good.

In view of the relatively inexpensive nature of the apparatus required, it is considered that the method is deserving of much wider use, particularly when the demand for oxygen determinations does not justify the construction of a vacuum-fusion apparatus.

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Gray and Sanders[4] modified the procedure in order to determine the oxygen content of solid steel. They fused thin slices of steel with excess aluminium in graphite boats at temperatures of the order of 1100° C, using an atmosphere of pure hydrogen. The same authors and Stevenson and Speight[5] later simplified the method by carrying out the fusion with aluminium *in vacuo*.

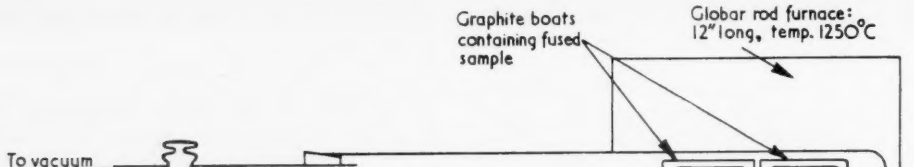


Fig. 1—Design of apparatus

Gotta,[6] while using a similar principle, departed radically from previous procedure by heating thin strips of steel in a powdered mixture of 1 part of aluminium with 3 parts of alumina. The steel samples buried in this mixture were heated to 1300° C in an alumina crucible in an electric furnace. The aluminium diffused into the steel, combining with the oxygen present. The alumina formed was then determined by wet methods.

The present author has further modified the aluminium fusion method described by Stevenson and Speight,[5] in order to facilitate the analysis of larger numbers of samples.

This has been accomplished by using mullite refractory tubes, which are better able to withstand the necessary temperature and pressure conditions than the silica tubes previously used. These new tubes have made possible the fusion of two samples at one time and the use of temperatures up to 1300° C, thus increasing the number of determinations which can be completed in a given time.

APPARATUS

The apparatus (Fig. 1) consists of a mullite refractory tube, 24 in. long and 1 in. internal diameter, which contains the two graphite boats and the samples. One end of the tube is closed, and the other is sealed with a rubber bung which has previously been smeared with silicone vacuum grease. The bung is fitted with a glass tube connected to a **U**-tube pressure gauge and a two-way tap which is used for connecting the apparatus to the mechanical oil pump.

The boats, which are 3 in. long with a wall thickness of $\frac{1}{8}$ in., are machined from a half-section of a 1-in. dia. bar of Acheson *T* grade graphite. The tube and contents are heated by means of a Globar rod furnace 12 in. long.

SAMPLE PREPARATION

Discs approximately $\frac{1}{10}$ in. thick are cut from a $\frac{1}{2}$-in. dia. bar which has been carefully ground to remove any surface oxide. The discs, which are cut just before use, are washed in ether before the determination.

The aluminium is prepared by cutting pure aluminium sheet $\frac{1}{8}$ in. thick into suitable sized strips. These strips are lightly filed on all surfaces just before use.

PROCEDURES

Four graphite boats (two containers and two lids) are placed in the refractory tube which is sealed and evacuated until the pressure falls to 1 or 2 mm Hg. The tube and contents are then placed in the furnace, which is switched on and controlled at 1250° C for 1 h. The furnace is then allowed to cool to 900–1000° C when the refractory tube is withdrawn. At this stage a second tube can be inserted and four more graphite boats can be degassed in the same manner.

When the first tube is cold, air is admitted, the graphite boats are withdrawn and any deposit on them is removed with a clean wire brush. Approximately 10 g of sample, sandwiched between aluminium strips weighing about 14 g, are put into each boat, and the graphite lids are replaced. The boats are then introduced into the refractory tube, which is sealed, evacuated, and placed in the furnace. The

Table I

COMPARISON OF TOTAL OXYGEN RESULTS OBTAINED BY THE ALUMINIUM REDUCTION AND VACUUM-FUSION METHODS

Sample	Type of Steel	Aluminium Reduction		Vacuum Fusion: Oxygen, %
		Blank: Oxygen, %	Corrected: Oxygen, %	
Cu2	0·51% Cu	0·002	0·008 0·009	0·010
Cr5	0·58% Cr	0·002	0·013 0·011	0·012
784	Basic open-hearth: 0·23% C, 0·66% Mn, 0·15% Si	0·003	0·011 0·011	0·011 0·011 0·010
J5926	Basic electric: 0·40% C, 0·65% Mn, 0·26% Si	0·002	0·004 0·004	0·004
H264	Basic electric: 4·75% Ni, 0·17% Cr	0·003	0·005 0·006	0·0055

temperature of the furnace, which should be of the order of 900° C, is rapidly raised to 1250° C and maintained for 2 h. After cooling to 900–1000° C, the refractory tube is withdrawn from the furnace and placed in an asbestos rack to cool. Care should be taken to maintain the tube in a horizontal position in order to avoid spilling the aluminium, which is liquid at this stage. A second series of samples can be treated in the furnace while the first tube is cooling.

When the tube and contents are cold, air is admitted, the boats are withdrawn, and the samples are removed for the determination of alumina. The boats, after cleaning with a wire brush, can be immediately re-used for a further set of samples.

It will be found advisable to evacuate the refractory tube continuously during the first half-hour of the heating cycle.

After this period, the pump can be shut off by means of the tap (*see* Fig. 1), but careful watch should be kept on the vacuum gauge, and any tendency for the pressure to rise should be countered by switching on the pump.

It should be emphasized that:

1. Only freshly degassed boats should be used for a determination
2. Exposure of the degassed boats to air should be kept to a minimum
3. Samples and aluminium should be freshly prepared
4. The furnace temperature should be in the range 900–1000° C when the refractory tubes are inserted or withdrawn. This procedure is adopted in order
   (*a*) to speed up the determination, and
   (*b*) to minimize any loss of oxygen as carbon monoxide from rimming and semi-killed steels.

DETERMINATION OF THE BLANK

The blank is determined by fusing 14 g of prepared aluminium sheet with a small weight of steel of known low oxygen content.

DETERMINATION OF ALUMINA

The fused samples are placed in a 1-l. beaker and dissolved by gently warming with hydrochloric acid, to which 10 g of citric acid has been added. When dissolved, the solution is oxidized with nitric acid, and a few millilitres excess are added. After diluting to about 600 ml with hot water, the solution is boiled gently for a few minutes, and filtered through an ashless paper pulp pad. The residue is washed with hot hydrochloric acid (1 : 1) until the filtrate is iron-free, and then with hot water to remove acid. Any precipitated silica is removed by washing with hot 3% sodium carbonate solution. The filtration is completed by washing with hot water and hot hydrochloric acid (1 : 1).

The residue is then ignited in a weighed platinum crucible and, after weighing, is treated with a few drops of sulphuric and hydrofluoric acids to remove silica. In the case of high-silicon steels and silicon irons it is advisable to add a few drops of nitric acid with the hydrofluoric acid to remove any graphitic silicon which may have been formed. After re-ignition and reweighing, the residue should be pure alumina, and the weight after deduction of the blank is used for calculation of the oxygen content of the steel sample. If the loss in weight after treatment with hydrofluoric acid is appreciable, the results should be regarded with suspicion, unless it is known that graphitic silicon was present.

COMMENTS

The aluminium reduction method operated *in vacuo* gives results which compare well with those obtained by the vacuum-fusion method (*see* Table I). Blank values are reasonably low, and the method can be used on a wide range of steels. The apparatus required is easily obtained, and the method is deserving of much wider use.

Some doubt exists about the applicability of the method to rimming and possibly semi-killed steels, in view of the ease with which carbon monoxide is evolved from some of these steels when heated *in vacuo*.

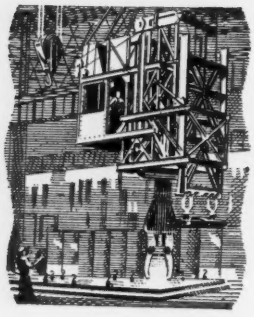
The extremely rapid heating should keep this evolution to a minimum. Nevertheless, it would be advisable to investigate the application of the method to steels of this type, and to compare the results obtained with vacuum-fusion results.

Acknowledgments

The author is indebted to Mr. H. H. Stanley, Chief Metallurgist of the Steel Company of Wales Ltd. (Newport Division), for advice and encouragement and to the Directors of the Company for permission to publish this paper.

References

1. C. H. Herty, H. Freeman, and M. W. Lightner: *U.S. Bur. Mines, Rep. Invest.*, 3166, April, 1932.
2. T. Swinden, W. W. Stevenson, and G. E. Speight: *J. Iron Steel Inst.*, 1943, No. II, 239p–242p.
3. G. E. Speight: *Ibid.*, 1948, vol. 160, pp. 390–396.
4. N. Gray and M. C. Sanders: *Ibid.*, 1938, No. I, pp. 348p–252p.
5. W. W. Stevenson and G. E. Speight: *Ibid.*, 1941, No. I, pp. 326p–328p.
6. A. Gotta: *Arch. Eisenhüttenwesen*, 1943, vol. 17, pp. 53–55.



The Iron and Steel Engineers Group

THE THIRTIETH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1, on Thursday, 15th March, 1956. Mr. W. M. LARKE, Chairman of the Group, was in the Chair.

This discussion was based on the paper by R. M. L. Elkan and J. T. Lewis entitled " Modern Forging Presses and their Control " which appeared in the February, 1956, issue of the *Journal* (vol. 182, pp. 200–215).

Mr. **R. M. L. Elkan** (Loewy Engineering Co. Ltd.) presented the paper, which was discussed in two parts.

Part 1

PRESS DESIGN AND CONSTRUCTION

Mr. **Elkan:** I would like to draw the attention of the meeting to a number of minor printing errors in the paper as published, and give the following corrections.

In Table I the working pressure should have been given as 300 atm for all calculations. In note (*f*) of this table it should have been stated that the motor efficiency was assumed to be 85%.

In the top left-hand corner of p. 204, column 1, reference is made to "*the largest single pump unit in the U.K. installed with five other forging presses working with the same drive* . . ." These words are misleading, for it was only the intention to point to the fact that all six presses worked on the direct water drive system; it was not intended to read that the other five presses worked off the same pump.

On p. 208, Fig. 6, there is a circle shown at the side of the number 6; this is extraneous and has no meaning.

On p. 211 at the foot of column 2, there is an expression for Reynolds number

$$R = \frac{7750vd}{\nu}$$; this should actually read $$R = \frac{7750vd}{\nu}$$

On p. 212, Force Diagram 11 (*c*) in the top left hand corner, the vertical reaction forces of 1136·5 *T* were omitted, and on p. 214, the small diagram at the bottom of column 2 should have been turned through 90° in an anti-clockwise direction.

The paper is essentially confined to free-forging presses, but I would like briefly to indicate some recent developments in die forging presses.

The presses in Figs. *A* and *B* are entirely automatic in operation, and although their performance was already good at the time of their installation several years ago, the performance possible from this type of press in terms of pressing and reversal speeds has been considerably improved by recent developments.

Figure *C* shows one of the 35,000 short-ton aluminium die-forging presses installed recently under the heavy press programme of the U.S.A. with the following principal characteristics:

Moving table	30 ft 6 in. × 12 ft 0 in.
Daylight	11 ft 9 in.
Stroke	6 ft 0 in.
Overall height	101 ft 0 in.

The four column groups each consist of three forged laminations about 100 ft long, a design which constituted a deliberate and radical departure from orthodox accepted column design.

Figure *D* shows the 50,000 short-ton aluminium die-forging press, also supplied under the above-mentioned programme. In this press there are six column groups each consisting of three forged laminations, the total overall length being about 110 ft.

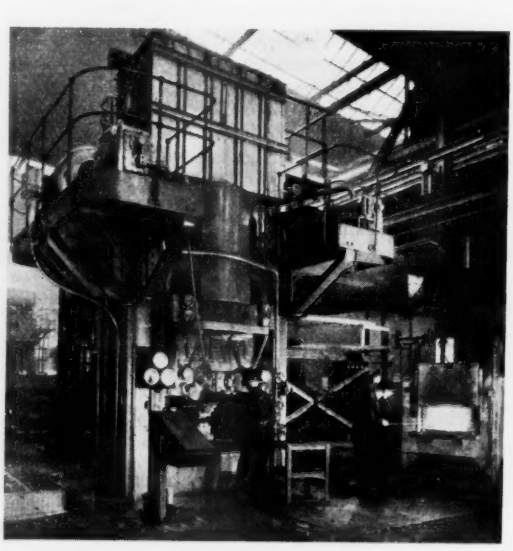


Fig. A—1000-ton oil-operated steel die-forging press

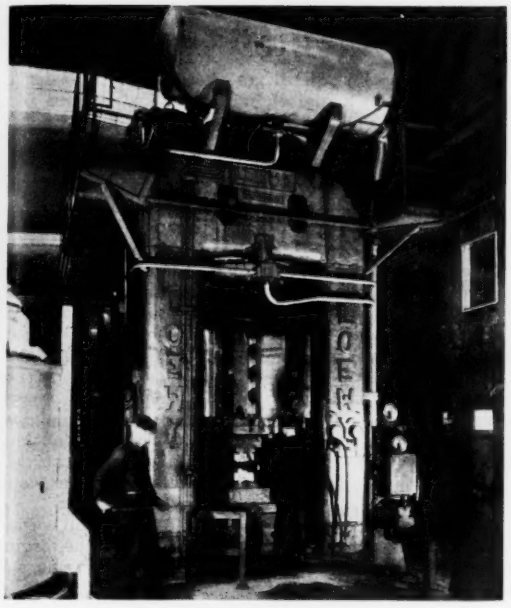


Fig. B—2000-ton water-operated steel die-forging press

As we have referred to accumulators in the paper, it is interesting to note that the accumulator station supplied for the above two presses consisted of 11 bottles each of 350 ft³ capacity, i.e. the total capacity installed was 3850 ft³. The characteristics of the bottles were:

Outside dia: 63½ in.
Height: 35½ ft
Weight: 76 tons
Working pressure of system: 4500 lb/in²

The bottles are made up of multi-layer laminations welded longitudinally and circumferentially, and have forged steel hemispherical heads which are welded to the main body of the shell. All the welds were carefully stress-relieved and radiographed through all stages of manufacture.

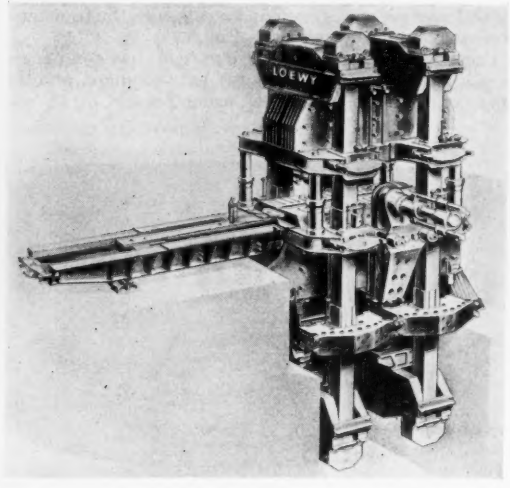


Fig. C—35,000 short-ton aluminium die-forging press

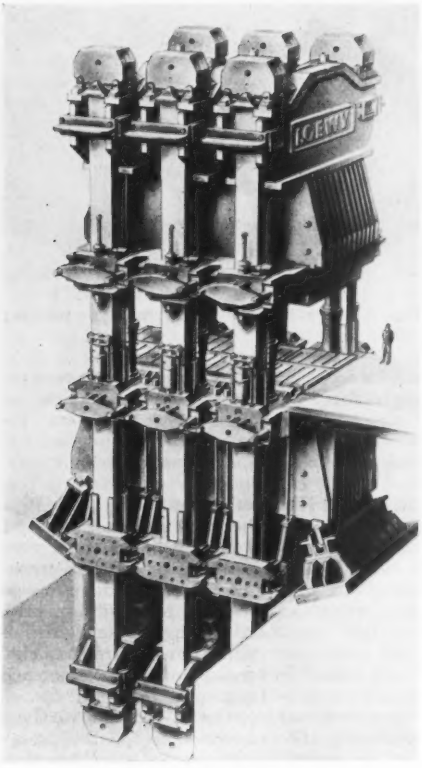


Fig. D—50,000 short-ton aluminium die-forging press

Seven pumps were also installed, each having an output of about 400 gal/min at 4500 lb/in².

Figure *E* shows the single **U**-ring type packing which is now no longer used in modern presses, as it required too frequent replacement. The average life figure was only in the 80–150 forging-hour range, depending on working pressure, diameter, condition of ram and bushes, nature of forging work, rigidity of press, and degree of cleanliness of water; the packing failure experienced with this type of ring was often sudden.

Figure *F* shows the modern lip-type expanding packing, in which generally four rings are used, excluding the header. The average life figures for these packings are much longer than for the single **U**-ring type, being normally at least in the 1500 to 3000 forging-hour range for presses up to about 5000 tons, and in the 700 to 1000 forging-hour range for larger presses.

Maximum recorded life figures are greatly in excess of these, but conditions vary vastly for the reasons already indicated.

In the U.K. to-day, there are only three major free-forging press units above 5000 tons, two of which are reasonably old even by forging press standards. There is little doubt that there exists a real need in the U.K. for a larger press or presses. There are two 6000-ton presses at present available which can comfortably handle 125-ton ingots, and less comfortably, say 150 to 180-ton ingots. There is a 7000-ton press which can comfortably handle 150-ton ingots, and again less comfortably ingots, say, of up to 200 tons, though to the credit of all concerned, as we know, ingots even up to

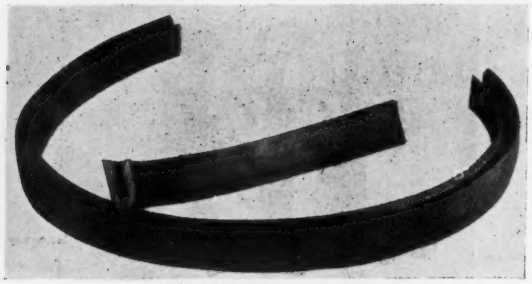


Fig. E—Obsolete single U-ring type packing

270 tons have been handled successfully in that press. The largest ingot available in the U.K. at the moment would appear to be about 280 tons, and there is undoubtedly a very urgent and strong case for a press of 12,000 or possibly 15,000 tons' capacity.

Mr. **R. Benson** (The Darlington Forge Ltd.): Regarding the side deflection of the press I note that the figures of deflection are for static loading. High planishing speeds of 100 strokes/min have been mentioned; have calculations been made to see if there is a periodic vibration, when the period of sway of the press synchronizes with the speed of the stroke? If this does occur, the movement will be much more than the figure mentioned, viz. 0·36 in. for static deflection, and may easily be the cause of fatigue.

The presses shown have no dial to indicate the stroke, and apparently the only guide to tell the press driver when he has completed his stroke is a chalk mark and pointer on the press column. It is illogical to provide finger-tip control to remove physical work for the press driver but still ask him to make the unnecessary effort to give accurate sizes, which this system entails. The result in practice is that the press driver slows down the press so that accurate control is easier and less concentration is needed, and in doing so, he nullifies the provision of higher speeds which has been made by the designer. This slowing down is not quite so necessary if a dial is fitted, because the movement is magnified and easier to see, but to get the full value of presses designed for high speeds, the stopping of the press at the desired point should be performed without effort by the driver. Perhaps Dr. Bramley will elaborate on this subject later; the system of control which seems to be needed is somewhat similar to one kind of position control which he has demonstrated as applied to the screw-down gear of a rolling mill.

By moving a finger-light control, the press driver should be able to control the position of an indicator finger on a dial similar to those fitted to some forging presses. The press crosshead must follow this movement at the maximum speed of which the press is capable and stop automatically when the desired position is reached. This would be indicated by a second pointer of normal type indicating the *actual* position of the crosshead. The operator would then reset the master pointer, by his controller, to give the desired position of lift. The crosshead should rise, again at maximum speed, to the 'up' position, the indicator pointer showing this movement as it occurs. The height of 'rise' might be controlled for each stroke, or alternatively, preset to give a definite amount of lift after each stroke. The operator would thus exactly control every stroke of the press, but without physical effort and at *maximum* speed. He would not have to look away from the actual job being done, because the dial would be placed alongside the press. The forgeman would probably prefer to drive the press himself, thus dispensing with a press driver, because it is easier to preset a size on a dial than to give instructions to a press driver as in present normal practice.

Tool changing is important to the practical operator. The provision of three sliding tables which can be moved separately or coupled together is good, especially for expanding work where two supports are needed under the ends of the bar and sometimes they need to be moved together, but at other times to be separated.

The speed of the sliding table is not mentioned, but it should be high. On many old presses it is too low, which is a great handicap because much forging work has to be done with the top and bottom tools deliberately placed out of line.

The method of securing the bottom tools is not mentioned, but appears to be the usual one of crossed grooves in the tool base and raised keys on the sliding table. This has certain disadvantages; do the authors know of further developments? Securing the top tools is even more important; again, are there any developments?

Tools have to be changed from time to time; in certain forging work they have to be changed during the forging operation. Five minutes saved between heats is five minutes operating time saved, but five minutes saved by quicker tool changing during a heat may be the vital five minutes which enables the job to be done in one heat instead of needing a reheat.

Methods of fastening, releasing, and changing tools will repay study and development.

Mr. **J. G. Frith** (Duncan Stewart and Co., Ltd.): In Table I, Mr. Elkan and Mr. Lewis give the principal features of a range of standard presses and these particulars correspond very closely with those in similar lists prepared by other press builders. This would show that so far as the manufacturers are concerned, a considerable measure of standardization has been reached, but as the authors have mentioned, these standards frequently require modification to meet the individual requirements of the users and can therefore serve only as a general guide.

It is, however, surprising to see in this Table that the stalling pressure when upsetting is given as 2–2½ tons/in² on the ingot, as this operation has been carried out at much lower pressures even on presses with the previously accepted forging speeds of 3–4 in./s.

Cases are on record where upsetting has commenced at a pressure of 1–1½ tons/in² on the ingot and has finished as low as ¾ ton/in² using presses fitted with

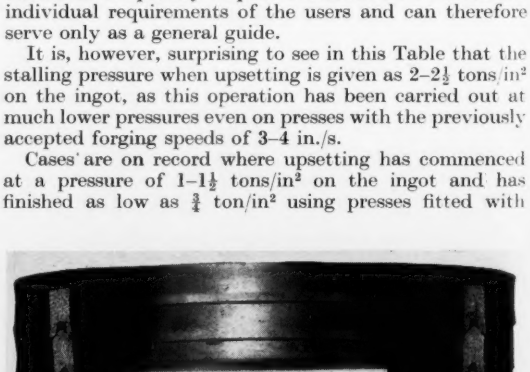


Fig. F—Modern lip-type expanding packing

steam–hydraulic intensifiers, where a number of successive squeezes are required to obtain the required reduction. Of course, this is not good upsetting practice as the material should be kept moving once the process has commenced, but it has been done, and although the speed of operation at such low pressures is admittedly not great, I would suggest that the stalling pressures quoted in the paper are rather high.

A further point of interest in Table I concerns the stated sizes of the accumulators which are apparently based upon $\frac{2}{3}$ of the full upsetting stroke. Surely a larger accumulator would be an advantage, as the pumping equipment presumably consists of multiple units and the greater accumulator capacity would give more margin between the pump 'on' and 'off-load' positions with less chance of rapid alternation between these points.

I agree with all that the authors have said on higher outputs from modern presses, except that it is not quite clear what is meant by a "more extended use of moving table gear". This type of gear has been fitted to presses for very many years and its use on the larger presses has been considered a standard requirement. It seems, therefore, hardly appropriate to include this item in the section referred to.

The utilization rate of the usual forging press is very low, largely owing to deficiencies in handling equipment and to the lack of furnace capacity.

It is interesting to note from Table I that 20% of the operating hours has been taken as the period in which the presses are forging. This, of course, is a figure assumed for comparative purposes, but if it has any basis in operating experience it shows that outputs could be materially increased by attention to the ancillary equipment. It is interesting to note in this connection that the steam requirements for steam–hydraulic intensifier presses were based on the utilization of 15–20 min full power operation per hour, and also that Dr. Stone in his paper on the 14,000-ton forging presses in the U.S.A. mentioned a figure of 15% as the ratio between the operating and total hours of the press. These figures show that outputs could be greatly improved if more attention was given to the furnaces and the handling equipment generally, and there is a big field here for study when new forges are put down.

Where the method of driving the press is concerned, it is true that the choice is now largely between the pump–accumulator and the direct pump systems. The steam–hydraulic intensifier had certain advantages such as a very short hydraulic circuit and a very efficient method of de-compression, but the trend now is away from this type of press because of the trouble and expense of steam raising. It is, therefore, only considered practicable in special circumstances.

There are two installations using the direct pump drive which are not mentioned in the paper.

One is a 1000-ton press in Sweden with small high-speed oil pumps, and the other is a 7000-ton press built and installed in Canada two or three years ago.

This latter unit has a pressing speed of about $1\frac{1}{2}$ in./s which may be considered slow, but was regarded as sufficient for the purpose. It is operated by three 3-throw horizontal ram pumps, each of 1400 hydraulic h.p. and each delivering 270 gal/min at 6000 lb/in². Strangely enough for pumps of this type, the hydraulic fluid is oil.

In connection with the direct pump drive, the paper states that a required capacity of 1600 gal is a practicable limit and that this would require eight 200-gal/min pumps basing on a pressure of 300 atm. The pumps on the Canadian press mentioned have a capacity, however, equivalent to 380 gal/min at 300 atm and the 1600 gal could, therefore, be obtained from four units with a considerable reduction in space. The stated limit for direct pump operation could probably be lifted.

The question of press drive has a considerable bearing on press design, and to some extent the two things are mutually contradictory. There is no doubt that the best press to withstand eccentric loading is one with a central guide stalk in which the load is either carried solely in the top member of the press, which is the best for very large presses, or between the top of the guide stalk and the column bushes. This design suggests the use of two cylinders which, from the point of view of the press alone, is undoubtedly the best arrangement, but does not adjust the effort to the work being done unless some flexible means of driving the press is used. This is, of course, given by the direct pump drive either with flywheels on the pump reduction gears or with complete Ward-Leonard equipment on the pump motor.

A twin-cylinder press with Ward Leonard operation of the pump would be ideal but costly.

With the pump and accumulator drive, the twin-cylinders are a disadvantage because full power must be used at every stroke irrespective of the work being done. The three-cylinder press is therefore adopted with this method of operation to enable forging to be carried out at $\frac{1}{3}$, $\frac{2}{3}$, or full power, and some designs use the centre cylinder as a guide. This involves two functions on one unit, in that the cylinder and ram must be pressure-tight but must also act as a guide with the possibilities of side wear and is far from ideal.

Press drive and press design are therefore closely allied, and must be considered first from the view point of the duty required from the press. If the ability to withstand heavy eccentric loading is required, the press design is the first consideration and the drive must take care of itself. If less eccentric loading is to be encountered, the three-cylinder press can be used but each case must be considered on its merits, and a hard and fast rule cannot be laid down.

The press that Mr. Elkan has described is most interesting, and the design of the columns without nuts or collars is at first sight attractive. I suggest, however, that column breakage is not a normal occurrence and that the collars and nuts so often used in the past are not a great disadvantage. They have, too, a definite advantage, in that the portions of the columns which fit either into top or bottom members of the press may be made to grip these members tightly by pre-stressing. If the column simply passes through the member, it must, of course, have an assembly clearance, and if no top and bottom grip is applied this clearance must increase in the course of time due to the swaying of the press. This change will be cumulative.

Swaying may not be a great disadvantage to the press itself but it can affect the joints in the pipes leading to the top of the press, and there is still a good deal to be said for the columns with nuts and collars which give a more rigid structure.

The next point I would like to raise is the method of holding the press down. I notice that the foundation bolts are considerably exposed above concrete level, and I presume this is done purposely to allow the bolts to be stretched. Has any trouble been found due to the whole press rocking on its supports, particularly as those supports are not extended very far beyond the column centres? I suggest that a wide base would be an advantage.

Method (1) is a very good method of calculation of the column loading, and the abbreviated method in which the deflection of the top and bottom members is ignored is a very quick way of getting an approximate result which is sufficiently accurate for most purposes. It is

very interesting to find that Dr. Stone's method gives the same results when the same assumptions are made, but method (1) is virtually standard today and is much simpler.

In Fig. 11 of the pre-circulated paper there is no indication of the power of the press in space diagram (*a*). This shows an eccentric load of 2000 tons and presumably refers to a press of 4000-tons power with half the load on one pair of opposite columns.

Mr. **L. S. Pell** (Hadfields Ltd.): Although this paper is on high speed forging presses and hydraulics in general, a large section is devoted to a forging unit installed in Sheffield about 5 years ago. This particular unit comprises two presses, of 2700 tons and 1500 tons capacity, and the allied air–water hydraulic accumulator system. Both Mr. Elkan and Mr. Lewis, along with their friends from Bournemouth, were responsible for the conception, design, and installation of this plant. For the first four-and-a-half years of its life, I was in charge of general maintenance. Apart from one or two teething troubles, this unit has given the utmost satisfaction. Speeds and rates of forging far in excess of those envisaged have been attained.

There was some trouble through excessive erosion on the main inlet valves caused by the high velocity of the water through the holes in the valve seating—illustrated on p. 207 of the paper. In an attempt to reduce this erosion, several experiments were made, first by spraying the valve at the point of water contact with 'Stellite.' While this eliminated erosion on the valve, the effects were transferred to the inside diameter of the valve seating. A second experiment was tried by means of drilling the holes through the seating tangentially to the centre of the seat. This, again, cut out erosion of the valve but resulted in a most efficient water motor. The valve assembly spun round merrily to the cost of rapid wear to the phosphor bronze retaining caps and very short life of pilot-valve spindle leathers. This problem was finally overcome by shrouding the bottom row of holes for 50% of their lower area.

Can the authors at this stage enlarge on the 'constant speed' valve mentioned to be under development? As a previous speaker has mentioned, there is a general feeling that the press operator should have speed and height control at his finger tips.

Finally, I refer to the necessity for adjustable column bushes in the base casting. Considerable wear takes place at this point because of the sway of the press. Wear of the actual column can only be restricted by means of a taper follow-up bush.

Referring to Mr. Frith's remarks on the question of trouble with pipe joints due to sway, I can say that during the five years that this plant has been operating, pipe joints have given no trouble whatever.

Dr. **L. N. Bramley** (B.I.S.R.A.): This paper is a fine exposition of the subject but it has not considered sufficiently the very important aspect of press control. This part of press design requires improvement.

There has been much talk about automation which is, of course, a process which has been going on for years, although many are just becoming conscious of it. Automation means taking away the simple or routine operations from the human operator and letting him do the more complicated things to which he is more suited. The simple operations bore and tire him, so that his efficiency decreases. A man is a very efficient compromise in that he can do a large number of things well; but when a machine is designed to do one thing only, it will beat him every time.

Working a forging press is one of those instances where a certain operation is repeated hundreds of times. A lever is pushed forward, the press head comes down to a chalk mark, and then the lever is pulled back. My opinion is that the control of most of these presses is crude, and may be considerably developed.

The forging press is a device in which the press head is required to be moved from place to place, and there is no doubt in my mind that the control which the man moves forward should also suffer a displacement. If a press has to be moved 6 in., then there is a big advantage if a calibrated dial can be turned on 6 in. and the press moves up to its new position. Obviously this will give the man much more time to think about the many complex operations involved in forging, since he does not have to watch the displacement taking place and terminate it at the proper time. Manual control of a forging press is an extremely skilled operation, and a single mistake on a big forging can cost a great deal of money. The operator is nearly always working in three dimensions, and variations in the pressing load mean that he must watch every stroke. If remote position control be applied to the press head, the travel will be almost completely independent of the load, so that the operator, who has always got at the back of his mind the thought that he might overshoot, can forget that worry completely. The system can be made so that it is automatically protected, and the press will go up to a certain point and no more. This is an important advantage. As an example, if a hollow cylinder is being forged, work is in three dimensions; rotation, stroke, and long travel have to be watched and worked together. Besides these are the many operations in the mind of the press operator which will lead to a successful forging. If there is remote position control on the rotation, the press head travel and, if necessary, on the crane long travel, it will be possible to work the travel of the press to a much higher order of accuracy and the forging may be rotated much more evenly. The net result will save a great deal of time in forging, will ensure a more even product, and will require less machining. I believe, too, that heats could be saved in many instances by using the press to its full capacity every time. With present practice the operator has no time to make a correction. He moves or turns the forging and if it looks about right, as it usually does, he operates the forge. With remote position control it is a matter of great simplicity to turn the forging to, say, $20° \pm 1°$ or $2°$.

On the question of travel of the press head, much greater accuracy is possible than is now attained. A new wind tunnel at present being built in this country, which has a hydraulic control of great accuracy, will serve as an example. It has two steel plates to profile the tunnel and every yard along the plates there is a hydraulic jack. As the Mach number of the tunnel is varied, so a different profile is required. All the jacks are on an automatic system, but a tape is fed into the controller and immediately all the jacks take up a position which profiles the tunnel on both sides. The travel of the jacks is as much as 20 in., and they are being set to a few thousandths of an inch. Thus with hydraulic control it is quite easy to get a control of more than 1000 to 1, which is certainly not required on a press. A travel of 8 ft (100 in.) in a forging press, with an accuracy of $\pm \frac{1}{8}$ in., is 1 in 400, which is not difficult to achieve by remote position control. It would allow a lot more planishing to be done very rapidly. The forging produced need no longer look rough, and the heavy and expensive machining operations could be largely cut down.

I should like to believe that the manufacturers are investigating this matter and doing something about it,

even on a small press to start with, so that the possibilities of remote position control are fully explored.

There is an easy lead into this question of getting remote position control by applying it to the manipulator. For instance, one very fine manipulator is at Mr. Benson's works. It is very fast and is operated by a highly skilled man. It consists of several speed control levers which are well placed for the operator. The position controllers are 'on' and 'off' all the time; as many as three of them may be 'on' at once. Every time the man wants to make any motion of the manipulator, he operates the appropriate control, waits for it to add up to the position he wants, and then he turns it off again. If he had position control on all those motions, he would make one movement, and the motion would follow up. The speed of follow-up is a matter for the technicians to achieve.

Finally, it is not impossible to try position control on a large press, and it is not dangerous. After all, a man is going to push a lever and the lever is going to open a valve eventually, which will undoubtedly have a servo on it. It only requires some kind of feed-back back from the press head which will move the other side of that valve and turn it off again when the press head has reached the required position. Then the original lever will be able to be calibrated in position.

The point is that this does not call for a fundamental change in the design of the press. Remote position control can be applied to many present-day presses, but there must be the facility for feeding back the position of the press head. In any future projects, I ask that press designers will incorporate that facility, because remote position control is surely coming in on heavy forging presses.

Mr. **A. Bennett** (Walter Somers Ltd.): In the illustrations of the presses, the method of holding the tools is that which has been followed for many years. This design is satisfactory while everything is new, but in the course of time, due to wear, it is impossible to maintain a bearing on all three faces. As a result, a gap appears and a large area is lost for distributing the load on the tool holder which leads to distortion of the tool particularly when eccentric loading occurs.

An improved method of fitting is achieved by making the dovetailed portion as wide as possible and to be the only bearing surface, the end portions of the holder to have a small clearance and reduced to the minimum width necessary for fitting folding keys. By this means, the load of the press is spread over the maximum possible area at all times and tool fitting is facilitated.

On the matter of ram packings, I cannot agree with the authors that it is necessary to have more than one packing ring for the main ram. Early hydraulic presses were fitted with a **U**-leather and this design was retained for many years. It was, however, difficult to provide a satisfactory support to the rounded base of the **U**-leather. If the top surface of the gland ring were to be machined to the corresponding semi-circle, two razor edges would be formed and these weak sections eventually lead to trouble. It was therefore usual for the sides of the groove to be formed at an angle of 45° and the sharp edges removed by a small radius. Under pressure the **U**-packing was forced into these spaces which distorted the leather fibres and ultimately caused failure.

Mr. Elkan exhibited a slide showing multi-ring packing, but surely it is the first ring that does the work, the others merely taking up some of the leakage which may get past the joint in the top ring. In contrast, a moulded fabric ring has a much longer working life, a flat base which is easy to support, a spreader ring to ensure expansion and, what is more important to the maintenance engineer, there is a warning leakage when this type of packing is likely to fail. In early presses it was not unusual for the **U**-leather packing to blow out during a heat. Furthermore, there is the cost of only one pair of rings instead of probably four as required by the multi-ring packing.

Like Mr. Frith, I prefer the prestressed column to that having top and bottom nuts with tension rods. In addition to prestressing the columns slightly more than the maximum loading imposed by eccentric forging under the press, the seatings for the nuts should be made conical and by providing surfaces more nearly normal to the flexing of the columns, may thus prevent any movement between the faces of the nuts and seatings on the base of the press. Should any movement occur on a press on which these surfaces are flat, they soon become affected by wear and result in loose columns which are difficult to rectify.

Dr. Bramley has put forward a very good case on automation which will be advantageous where large numbers of the same piece are to be produced, but manufacturers of heavy forgings are faced with the problem that they seldom get two jobs alike. When this does occur they cannot expect to have every condition exactly the same for each piece to be produced. That will provide the greatest difficulty in applying automation with positional control, in the manufacture of large heavy forgings.

Mr. **W. H. Alvey** (English Steel Corporation Ltd.): The first question I should like to ask is whether the authors know of any forging presses over 7000 tons which have a penetration speed of 6–8 in./s ?

Whilst forging press designers can undoubtedly provide such speeds, it is important that the forging cranes synchronize with the press if advantage is to be taken of these working speeds. In the past, on cranes up to 300-tons capacity, crane designers had difficulty in providing suitable speeds for manipulating heavy forgings to match press forging speeds of 2 in./s with press lifting and lowering speeds of 6–8 in./s. It is, therefore, doubtful if there is any advantage to be gained with fast-speed heavy forging presses unless the handling facilities can be provided to match.

The author's accumulator system certainly has some advantages, particularly when making long upsetting strokes, but for general forging work there is still much in favour of the direct pump drive.

More consideration of the economics of the two systems is required, particular attention being paid to the frequency of upsetting strokes compared with general forging strokes. Have the authors compared the capital cost of the accumulator system with that of the direct drive ? One disadvantage of the air-hydraulic system for large presses is that it requires three pressure stages to give some measure of economy in working.

I agree that it is not good engineering practice to have rams performing a dual job; the function of the ram should be to transmit the pressure to the top tool only and not to take horizontal stresses due to eccentric loading.

Further information on the fixed ram with floating cylinder shown by the author would be interesting.

In forging presses of 7000 tons and over, considerable allowance must be made for expansion between the crosshead and the columns. This can be $\frac{3}{8}$ in. or more. Because of this, it seems to me that with the authors' press design the centre ram must be called upon to resist some of the off-centre loads which may result in high transverse stresses being developed in the rams.

The comparison given in Table I between a 6000-ton

press on direct drive and one on accumulator drive, is of interest; the paper suggests a power consumption of 605 kWh per average operating hour for such a press using penetration speeds of 2 in./s.

Throughout 21 years of operation, the 7000-ton direct pump drive press at the English Steel Corporation has averaged only 138 kWh as compared with the above figure given in the paper for a smaller press. The average figure I have quoted refers to operating hours, i.e. the time the forging crew are on duty. Since forgemasters have different methods of measuring forging time, the average figure quoted becomes 165 kWh if the time is taken from picking up the ingot from the furnace, forging under the press, and putting back into the furnace or down on the shop floor.

Whilst quoting figures, it may be interesting to mention that in my paper "A Modern Heavy Forging Plant"* I gave some figures of the actual tons of ingots forged in our 7000-ton press since it was converted to direct electric pump drive. Now, after 21 years working, this press has dealt with 437,234 tons of ingots and produced 250,937 tons of finished forgings at an average of 25·6 kWh units per ton of ingot weight. The English Steel Corporation has six forging presses working with similar direct pump drives and which, in all cases have been free from maintenance trouble of any kind, thus emphasizing the reliability and economy of this system.

Would the air–hydraulic system be as reliable or as economical to run ?

Mr. **M. D. J. Brisby** (Iron and Steel Board): First I want to deal with a point on the mathematics of this paper. I am not really convinced that the Moment Distribution method is the best solution in the case of very simple closed frames. This is a matter of opinion, but I should have thought that for this type of frame the straightforward Clapeyron Three Moment Equations would have been simpler. The equations can be set out in matrix form as follows:

X_1	X_2	X_3	...	X_n	...	$6E\Delta$	W (load function)
A_{11}	A_{12}	A_{13}		A_{1n}		C_1	
A_{21}	A_{22}	A_{23}		A_{2n}		C_2	
A_{31}	A_{32}	A_{33}		A_{3n}		C_3	
.							
.							
.							
A_{n1}	A_{n2}	A_{n3}		A_{nn}		C_n	

The matrix can then be solved for the coefficients of the unknowns, A_{11} A_{12} A_{13} etc., by successive elimination. Sidesway in the frame can be catered for automatically by the inclusion of an additional term $6E\Delta$ in the equations. The solution of the matrix then gives the node moments and the amplitude of sway. The advantage of the method is that the matrix is set up once for all; the only variables are the geometry of the frame and the different conditions of loading.

The second point I wish to make is more serious. All the classic methods of solution, e.g. Moment Distribution, Three and Four Moments, Slope Deflection, Strain-Energy, Column Analogy, etc., imply the basic assumptions of Hooke, St. Venant, and Navier. Now the press frames examined by the authors are far from satisfying the essential condition of being prismatic sections. And, therefore, I fear that the hypothesis of the calculation is incorrect. If a mathematical model is of doubtful validity it is probably better to do without and resort to rule of thumb and practical experience.

Finally, I should very much like to know the authors' view on the future of heavy presses. Welding has made progress by leaps and bounds and it would be interesting to know whether we shall require to forge ingots of 350 and 400 tons in the future.

Mr. **W. Melville** (I.C.I. Ltd., Metals Division): The authors have pointed out that in practice both accumulator and direct pumping systems suffer from similar throttling losses unless some method of varying the rate of pumping is used in the latter case. It is perhaps worth enlarging on the characteristics of these two systems and Fig. *G* shows the throttling characteristics with direct pumping and accumulators, neglecting any other losses due to pipe friction, compressibility, and such causes. It will be seen that the two systems have opposing characteristics in that one is sensitive to speed and the other to cylinder pressure. This suggests that where the usual working pressures tend to approach the maximum design figure and the speed varies according to the resistance, a state of affairs which I imagine exists with forging presses when working to capacity, the accumulator system is likely to be more economical. A statistical analysis of the working conditions for any particular case could probably give a useful guide in choosing between the two systems.

The press cylinder, as usually designed, can be a source of expensive trouble. There is a sharp stress concentration at the junction between the cylindrical body and the blind end, and it is rare to see any better form than the imperfect hemisphere. The cylinders illustrated by the authors are orthodox and I should expect the ends to drop off some day, a trouble which has not been uncommon with extrusion presses in the firm with which I am associated. These cylinders should be designed with a transition form at the knuckle to avoid sudden stress changes, or as plain tubes with the end closed by a piston from the press columns where circumstances permit. If the authors have not had any cylinders fail by circumferential cracking, they have been fortunate.

I agree with Mr. Bennett in his preference for one packing ring instead of several. The experience which inclines me to this belief occurred with a 25-pounder gun, not a forging press, though the two machines have many points in common. With the gun, replacement of a double S.E.A. ring packing by a single ring gave greatly improved results. The friction was much reduced, and from an average life of 3000 to 4000 rounds the packing had lasted 18,000 rounds when I last heard of it. I believe the outer packings only add to the friction and act as wipers but the latter function can be carried out by more efficient means.

Mr. Benson mentioned the stalling of presses with direct pumps and I have been wondering where the water goes under these conditions. Does the operator watch the pressure gauge and regulate his bypass accordingly, or does he screw down the bypass and let the water escape through the relief valves ? If the latter, I hope the relief valves are more adequate than those usually supplied for extrusion presses which appear to be designed as a last hope rather than for regular use. Perhaps Mr. Elkan could give us some comments on the design of the relief valves.

Mr. **P. M. Cook** (B.I.S.R.A.): Would the authors elaborate on the specific pressure at different speeds of forging. In the paper, they state that for the ingot diameters after upsetting, the stalling pressures (2–2·5

J. Iron Steel Inst., 1949, vol. 161, pp. 119–138.

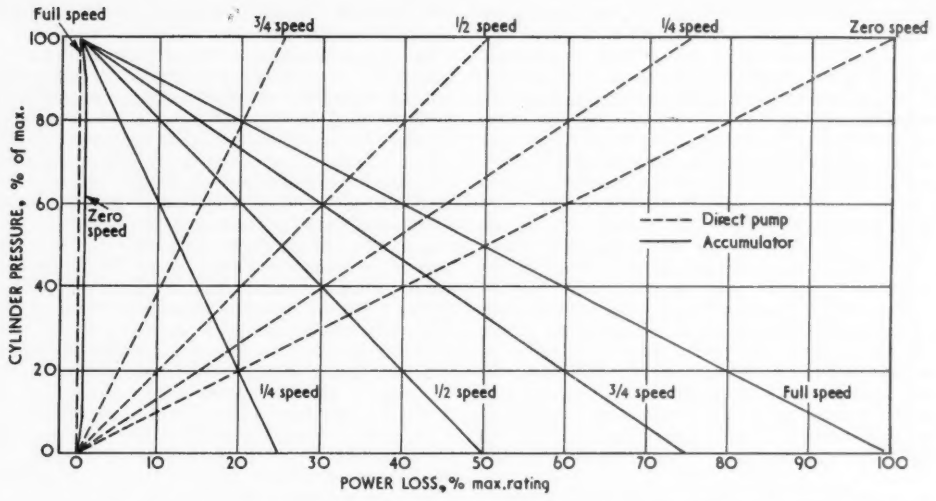


Fig. G—Throttling characteristics with direct pumping and accumulators

tons/in²) are generally accepted and give an approximate indication, but that on the more recent fast-acting presses (penetration speeds 6–10 in./s) it has been found that once an upsetting stroke has begun and is carried out continuously, the operation can be carried on down to specific pressures as low as 1 ton/in².

This seems to be the wrong way round. It is well established that at high speeds the yield strength of steel, worked at a constant temperature, will be higher than it is at low speeds. It would be interesting to know whether these particular figures I have quoted do, in fact, take account of the fact that on the slower stroke the material has more time to cool down, both by radiation and by the chilling effect of the tools. Is this effect a temperature effect and not a speed effect ?

Mr. **E. C. Houghton** (Vickers-Armstrongs (Engineers) Ltd.): I have not yet read the paper, but after hearing it presented and discussed I am not clear about one point. Mr. Elkan said that it was very convenient to be able to ' lose ' a lot of the adverse bending moment in the crown. Where does this go to, because the crown is still mounted on the columns ? As far as I can see, it is bound to result in a bending moment on the columns. Perhaps this is the most efficient way of transferring it, but it is doubtful that the bending moment in the columns is negligible.

In giving a list of heavy presses, Mr. Elkan did not mention the 8500-ton press which was installed a year or two ago in a Manchester steelworks. It was fortunate that direct central loading takes place, and no offset, eccentric loading was specified. Even so, in order to allow for the inevitable deflection of the crown and its consequent action on the columns, the frame was calculated simply as a Portal Frame. The result was to add 1 in. to the diameter of the columns. Whereas 26-in. columns would have been quite satisfactory to take direct central loading and ignore the transmission of any bending moment, the 26-in. columns had to become 27-in. columns. This supports my contention that they have to share this bending moment in the crown somehow.

Mr. Elkan referred to the overloading of the motor. I do not agree with him, as the motor was probably quite satisfactory. There is still far too much of a tendency in driving pumps and similar machinery by electric motors, to take the maximum requirement of the pump and make the motor either as big or even bigger. Nearly every press is working on some kind of cycle, and provided that the stalling range is not exceeded, the only way to overload an electric motor is by overheating it. As long as the root mean square value of the current taken over the cycle is within the capacity of the motor, the motor will not be overloaded. It may be a 60 h.p. load on a 20 h.p. motor, but as long as that condition pertains the motor will not be overloaded.

Finally, I do not know of any other way of obtaining a very rapid series of planishing strokes as efficiently as with the steam intensifier.

AUTHORS' REPLY

Mr. **Elkan:** A large number of interesting questions have been asked and points raised, and whereas we may have to reply to some of them in writing, there are others with which I can deal now.

Mr. Benson referred to the question of press sway, and the dynamic oscillations of the structure when planishing. We have investigated this and it is possible to calculate the natural frequency of the structure by using Rayleigh's approximate method. The weights of the press parts are considered to act at various points, and the frequency of oscillation evaluated by the well-known method. If possible, we endeavour to proportion the press parts in such a manner that the 110 to 120 planishing strokes per minute, or whatever one aims for, do not by a long way correspond to the natural frequency or to a close harmonic of this. However, the solution is to have the servo-gear sufficiently sensitive and responsive on either side of the natural frequency, to overcome any danger of resonant condition should such arise.

The speeds of the sliding tables as now supplied, vary between 10 and 12 in./s.

Mr. Frith's comments were very interesting; referring to the stalling pressure, we stated on p. 201 that once an upsetting stroke has begun and is carried out continuously, the operation can be carried on down to specific pressures of as low as 1 ton/in². Our wording may perhaps not have been very clear, but it is certainly agreed that it is possible to keep going down to pressures

even well below 1 ton/in², provided the heat content of the ingot and the press power allow this.

On accumulator sizes, column 8 of Table I assumes a useful accumulator capacity is based on an upsetting stroke of 0·75 to 0·8 × press stroke for presses between 4000 and 5000 tons; for presses of 5000 tons and over the accumulator capacity is based on 0·65 to 0·7 × press stroke. A number of empirical rules concerning the recommended proportion of upsetting stroke to press stroke exist.

The figures given in column 10 of Table I for the useful accumulator capacity are somewhat low when compared to installed accumulators for presses up to about the 2500 ton mark, and somewhat high for the larger presses. The former is because more pumping capacity is installed in modern accumulator plant, compared to some of the earlier installations, as much higher rates of production are required. This is partly the result of more effective circuit design enabling a given press tonnage to be utilized nearer to its full rating than of old, and partly due to better handling and manipulation within the press, also in the forge and furnace bays.

Mr. Frith states that he notes from Table I that 20% of the operating hours has been taken as the period in which the presses are forging. This is a misunderstanding; it is assumed that the accumulator pumps are actually pumping on full load for 20% of the operating hours, and as stated on p. 205 the number of actual forging hours (i.e. the time a forging is actually in the press) varies greatly from plant to plant, and is generally between 40 and 60% of the operating hours (i.e. the time the forging crew is actually available for forging operations). Thus 20% of the operating hours that the accumulator pumps are actually pumping does not necessarily mean a bad utilization of the press as such, and it is often the case that the pumping capacity installed is large enough to satisfy the quick forging and planishing conditions, and therefore the percentage of 'on-load' time for the pumps bears no fixed relation to the percentage of the time that the press is actually being used.

With Mr. Frith, I feel that it was strange that oil was used for a 7000-ton press installed in Canada two or three years ago. A pressing speed of about 1·5 in./s is certainly very slow by recent standards, and in this case the twin cylinder design does not make it possible to utilize the press at 2·25 or 4·5 in./s, at two-thirds or one-third press tonnage, which would have been possible with a triple cylinder design. The 3-throw pumps delivering 270 gal/min appear to be of the more orthodox water pump construction.

In the space diagram of Fig. 11 (*a*) a 4000-ton press is considered and the 2000 tons shown represent half the load on one column pair.

I think that Mr. Frith's comments on the pros and cons of the twin cylinder design press are certainly correct, and stated very objectively.

We are glad to have Mr. Pell's comments. The valve design as shown in Fig. 5 (*d*) of the paper certainly does look like a water turbine, and it is not surprising that Mr. Pell experienced a spinning of such a valve assembly, if care was not taken to lock the parts of the valve seating case by suitable pins. We had a recent example of the use of such a valve, when, for a special application, we were anxious to speed up considerably the operation of an extrusion press, for which a pressing speed of 15 in./s was required, and all possible expedients were adopted to cut down the losses between the accumulator station and the press. Thus all right-angle stop valves were fitted with streamline chambers as shown in Fig. 5 (*d*), but as mentioned before, care had to be taken to lock these by the use of suitable stop pins against them acting as turbine runners.

The small erosion trouble experienced with the main inlet valve in the plant with which Mr. Pell is associated was, as he stated, completely and permanently overcome by shrouding the bottom row of holes in the valve seat by 50% of its area, and now this valve satisfies all requirements, viz. sensitive control with a small amount of opening, yet low losses when high volumes are passing through per second when high pressing speeds are required. These same requirements can be met by a design of a valve of type (*b*) in Fig. 5, where, however, care is necessary to obtain the right curvature on the valve protrusion so as to satisfy all the requirements.

The constant-speed valve at present being developed is an electrically controlled hydraulic type, which will be used where it is required to operate a press at a constant speed, off an accumulator system. We would not like to say that it will yield constant speed within 2–3%, but the limit will be within 10%.

Dr. Bramley has focused our attention to the question of automation and remote position control. I think that his indications and prediction regarding future developments are correct. It is necessary to differentiate somewhat between a repetition product press, such as the 1000 and 2000-ton die-forging presses already illustrated in slides (Figs. *A*, *B* and the free-forging presses as discussed in this paper). The former are fully automatic and work on a form of position control, in that the operator can select beforehand the exact point at which the press is switched from its advance speed over to its pressing speed and pressure.

Dr. Bramley will find that some automatic extrusion presses work on a form of position control. Some of the works people are at first a little apprehensive of the complication, but we have now between 20 and 30 such installations, and the personnel are accustomed to them. This type of automatic control is employed whether water or oil is the working fluid, and is especially suited to extrusion presses which are very much engaged on repetition work where exactly the same discard thickness is desired, and the extrusion should be stopped at the same point, etc. This type of control has in fact been considerably developed for extrusion, drawing, and die-forging presses.

As far as the orthodox free-forging press is concerned I can visualize a certain amount of resistance on the part of the practical forging man; it is not possible to hand over too much of the know-how of, say, 30 or 40 years of practical experience to automatic devices, especially when such valuable items as 50- or 100-ton billets are being handled. It will not be possible in this type of work to dispense completely with the experience factor, for this is still the blacksmith's work, and the human 'feel' is very much part of the technique. All this does not in any way detract from Dr. Bramley's pointer, and I think that in the future we shall see progress made in the direction indicated by him.

It was very interesting to hear Mr. Bennett's ideas, particularly on methods of securing the tools. We are not always completely free to put forward certain details of design on a press as we would wish, for often the user to whom we supply a plant has strong ideas, and we may not always be able to tell him that his wishes do not correspond to the latest apparent developments.

On the matter of packings, it is extremely interesting to hear of Mr. Bennett's experience, and we would like him to tell us a little more about the comparative danger of failure of the types he illustrated, also the variations in working life. The choice of packing is governed largely by such factors as useful life, friction, and the hazards that would ensue upon sudden failure. As the friction

effect does not matter in a forging press, from this aspect there would be no objection to a multiple packing. In recent times we have frequently used a form of single-ring packing for applications where a ram had to fall by gravity, or where it was essential to keep the friction forces to a low value, but there is a definite trend in recent forging presses which favours the use of multiple packings.

In reply to Mr. Alvey, I would like to state that whereas we do not know of a forging press of over 7000 tons with a penetration speed of 6 to 8 in./s, we do know of an 8000-ton press working at 4 in./s. We have been approached by a number of forge operators who would like much higher speeds in their larger presses, and we have somehow to ensure that such higher speeds will be provided for upsetting work. We agree that the full advantage of high-speed heavy forging presses is only obtained when the handling facilities are provided to work at a pace much more in line with the press performance than has often hitherto been the case.

We have compared the capital cost of the accumulator system with that of the direct drive system, and as mentioned on p. 205 of the paper, direct drive can hold its own on first costs with the accumulator drive up to penetration speeds of about 3 in./s, but only for the lower press tonnages.

Mr. Alvey favours the direct pump drive, with which system he has for a long time been closely and eminently associated. However, we would hesitate to advocate rigidly the adherence to any one method of drive for all press sizes, for all penetration speeds, and irrespective of the many factors involved. It is not agreed that three pressure stages are necessarily required to give a measure of economy in working when using the air–hydraulic system for large presses. However, the availability of three pressure stages is certainly highly attractive; in some instances this would also apply to presses operated on direct drive, and where the availability of three pressure stages would make possible three speed stages, an expedient which is not available with the twin cylinder design.

On the question of running costs, and notably the comparison in Table I between a 6000-ton press on direct-drive and one on accumulator drive as mentioned by Mr. Alvey, the figures given throughout this Table were based on clearly stated assumptions, and as the cost analyses given were merely made to show the manner in which it is possible to get an approximate comparison, the 7000-ton direct pump drive press to which Mr. Alvey refers, which on an average requires only 138 kWh per operating hour, is compared to the figure of 605 kWh per operating hour set out in column 21 of Table I for a 6000-ton press. This difference is perfectly in order, for Mr. Alvey did not give the percentage of 'idling' to 'on-load' times for the 7000-ton press, i.e. the amount of work done per operating hour must be the same before any actual comparison is of value. It is the figure of 25·6 kWh/ton of ingot weight given by him, which is the real index to the efficiency of the press drive.

On the whole question of the economics of one form of drive when compared to another, it is important to remember that whether one uses 200 units for a particular operation or, say, 280 units for the same operation, this is not really of great importance when handling ingots say, up to 80 or 90 tons. If one can get more work done per heat with all that this implies in less waiting time, less handling time, or even the absence of the need to reheat, it will be seen that whereas the whole question of running economics is, of course, important, we must not concentrate too much on the kWh which costs 1*d*, and try to save 100, 200, or even 500 kWh, at the expense of having one or two more reheats. We must watch the economics of operation, but we must not be too influenced by 'localized' economics as opposed to overall plant economics, which includes the costs of furnaces, handling, and all the attendant manpower and administrative costs. The amount of power-saving between various forms of drive compared to the overall cost of running a plant, though significant, is not as important as one would anticipate, and any expedient which obtains more work per heat is of the greatest value. For this reason the high-speed air–hydraulic accumulator driven presses are proving so satisfactory in recently installed plants.

Mr. Alvey asks whether the air–hydraulic system would be as reliable as direct pump drive. The direct water pump drive system certainly is reliable, and no better proof of this was given than in Mr. Alvey's paper presented some years ago, in which some instances were cited of water pumps which had been running for 15 to 20 years with a remarkable record of absence of breakdown. The much maligned slow-running water pump has a great deal to be said for its reliability, which is very important in forging plant. As far as the air–hydraulic accumulator is concerned, there are now hundreds in operation in many lands, yet the accumulator system also has to rely on pumps as does the direct drive system, its other constituent parts are static, i.e. bottles and piping which certainly are not subject to wear. There may be five or six pumps in a station, and even if one or the other might be temporarily out of action, this does not involve a breakdown in the functioning of the plant. The reliability of air–hydraulic accumulator stations in charge of a good maintenance engineer is very high indeed.

It has been pointed out that it may be slightly detrimental that the central rams in the presses shown in Figs. 2 and 3 of the paper, have to transmit a certain amount of horizontal force due to eccentrically applied loads. By having a very large resistance arm (h in Fig. 11*a*) i.e. by having the reaction to the eccentric couple very high up in the platen and very low down on the column, it is possible to make the actual value of the force very small indeed. Furthermore, amply proportioned bronze bushes are provided, and bearing pressures may be considerably less than 0·5 ton/in^2. A mechanical structure may certainly be subjected to more than one force, including that due to fluid pressure, for as long as the sum of all the stresses and the resulting deflections is low, no harm whatever is done.

In reply to Mr. Brisby's comments that the Clapeyron three-moment equations would have been simpler, we would state that this and similar mathematical methods are not self-checking; they are accurate but they are also very sensitive in their evaluation, and it is necessary, for example in the case of the Slope-Deflection method, to use six- or seven-figure logarithms. It would have been valuable if Mr. Brisby, apart from setting out the matrix of his equations, had completely worked out one of the cases as given in the paper, when I believe that his method would prove too sensitive and lengthy in detail evaluation, apart from possibly being of too high a mathematical standard for industrial design offices where these problems are met and promptly have to be dealt with.

Although I feel I am not entirely qualified to judge, I do not share Mr. Brisby's pessimism regarding the assumptions made. A similar overall criticism could be levelled against the whole theory of bending, which after all is only an approximation yet is nevertheless used throughout industry. Referring to the use of mathematical models of doubtful validity and the advantage of adhering to rules-of-thumb, reference to column 2

of p. 213 of the paper will show that the rule-of-thumb-column stress would have been 1·82 tons/in², whereas the analyses used indicate actual column stresses of 8·42 tons/in². The calculated deflections have been checked with those occurring in practice and have been found to agree substantially; similarly, calculated stresses have been confirmed by strain gauge readings. I suggest that the methods of calculation used in industry may not always be based on academically faultless assumptions, and approximations may have to be used, but as long as these yield safe answers, e.g. within 10% of the actual stresses and deflections as found, they are surely adequate.

Regarding Mr. Brisby's question on the future of heavy presses and the use of weldments, there is a continuing trend for bigger and more powerful plant. Even when alternative methods of construction such as welding are available, this does not imply that heavy forgings will not also be required. There is little doubt that ingots of 350 to 400 tons will have to be forged from time to time.

As a matter of interest we employed some welded cross-members on several presses in recent years, utilizing welds to a depth of 7 in. which, by careful and adequate stress relieving treatment, yielded structures which are operating perfectly safely in production.

I am sorry that Mr. Melville has fears that the cylinders as illustrated in Figs. 2 and 3 have ends that might drop off some day. The illustrations are diagrammatic only, and there are certainly no flat ends. The cylinders are generally made of forged steel with a very generous radius at the closed upper end, and no trouble is experienced with cylinder failure as long as sudden changes in direction and other sources of stress concentration are avoided. It is also necessary to ensure that the depth of the flange is adequate, to avoid too much deflection by shear and bending.

Relief valves as used for extrusion presses have undergone considerable development in recent years, notably in their use with oil as the operating fluid. One must differentiate carefully between relief valves installed purely as a safety feature or ' last hope ' as Mr. Melville calls them, and those deliberately built into a circuit for the purpose of by-passing varying quantities of fluid under certain predeterminable conditions.

Mr. Cook must have misunderstood our comments concerning the stalling pressures when upsetting, which we stated as varying from 2 to 2½ tons/in² down to 1 ton/in². It has been found that once upsetting has started it is advantageous to continue, for the conditions are very different if one stops and starts again. We certainly would not try to claim that resistance decreases with speed; as he says, the effect at least partially, is a temperature effect. A certain amount of heat is generated as work is put into the ingot (perhaps the metallurgists will be able to tell us the exact amount) and there is little doubt that the slower the upsetting stroke, and for that matter a pressing stroke in general, the less heat is generated within the work piece, the more time the latter has to cool down by radiation, by conduction (i.e. chilling effect of tools etc.), and to a lesser extent by convection.

Mr. Houghton asks where the adverse bending moment goes to in the crown, and feels that this must result in additional bending moment on the columns. In fact the average crown, or upper platen, of a press is very rigid, i.e. its flexural rigidity is many times that of the slender columns, and thus the eccentrically applied moment results in an additional pull on one column pair and a corresponding push (a decrease of tension) on the other.

The reason the 8500-ton press installed a short time ago in a Manchester steelworks was not mentioned, was because this is a railway wheel press, and we have tried to confine ourselves in this paper to free-forging presses.

I quite agree with Mr. Houghton's comments that there is no such thing as overloading an electric motor, except in that this implies overheating it. In the assumptions made in Table I, the nominal installed h.p. rating was taken as 60% of the hydraulic h.p. which may mean that in some instances the h.p. load is in excess of 100% of the nominal h.p. of the motor.

Part 2

HYDRAULIC SYSTEMS

Mr. Elkan introduced the sections of the paper on hydraulic systems.

Mr. **Bennett:** Under the heading ' Working Fluid ' on p. 204, the authors recommend 2–3% of soluble oil to be added when water is used as the pressure medium. Whilst this is desirable initially when starting up a new plant, the proportion of soluble oil to water may, when working, be satisfactorily reduced gradually to 1%, or even as low as 0·5%, with corresponding economy, provided the oil used is stable at such dilution. Soft clean water only should be used, and the working temperature kept below 40° C, with 50° C as a maximum.

No mention of a filter is made by the authors. Although clean water is used for the initial filling, this in time becomes contaminated by foreign particles from the pipework, packing materials, etc., which, if not removed, can cause much trouble through ' dirt-lock,' particularly on valve mechanisms. I suggest that a filtering system should be incorporated, capable of dealing with the complete volume of water at least twice a day. What are the authors' experience and recommendations on this?

The authors point out that considerable damage often results when excessive pressures occur through water hammer when valves are suddenly closed or opened. To obviate this effect it is usual to install expansion or surge vessels, but even then water hammer can still persist. This high-pressure equipment can be very expensive to install and maintain as was shown in the paper by Mr. Alvey, which has already been mentioned. I am convinced that it is wrong to attempt to exhaust pressure water direct into an air-loaded reservoir or to an overhead supply tank, although the inclusion of expansion vessels does reduce the shock. In the latter case, the static head of water may be only a few lb/in² but the effort necessary to get this column of water suddenly on the move is very considerable, resulting in water hammer, fatigue of the various parts, and consequent failure.

It seems to me that stored energies from all sources can be quickly dissipated, avoiding water hammer, by exhausting to atmosphere through an open pipe direct into a tank below ground and situated immediately beneath the hydraulic-control valve gear. A small motor-driven pump is then necessary with suitable

water-level control to return the water to the reservoir or overhead supply tank. It is advisable to have a duplicate pumping set coupled up as a standby. This system has been used in connection with small hydraulic presses working from an accumulator at a pressure of 2 tons/in² with no trouble and a complete absence of water hammer and shock, even with quick reversals.

I described this arrangement at the time of the discussion following the presentation of Mr. Alvey's paper and I should like to know whether the authors have used such an arrangement in the circuits for large presses or, if not, what the objections are to its adoption.

On the matter of the comparative life of **U**-leather rings and single moulded fabric packing rings the following figures may be of interest. On one forging press the average working life of **U**-leather packing was 425 h; the method of packing was then altered to use a single moulded fabric ring and the average life increased to 3013 forging hours. On another press the lives were 726 and 2310 forging hours respectively. Many factors determine the useful life of packings but in every case where the single moulded fabric ring has been adopted a much longer life has resulted.

Mr. **Pell:** Comparing multiple and single packings, we have actually worked for 3 to 3½ years with one set of four packings, which means 9000 to 10,000 forging hours. That is a fair average on a 21-in. dia. ram.

Mr. **F. H. Towler** (Towler Bros. (Patents) Ltd.): The authors are to be congratulated on the objective way in which they have treated this subject. All makers and users of hydraulic equipment for forging suffer from a considerable lack of facts. Whereas steam engines from the outset were provided with indicator diagrams, there are very few published indicator diagrams for forging presses. Much of the talk about speed is almost pure conjecture; the users of hydraulic presses should find out how fast their presses really do work.

The figures of loss of rated power with maximum speed, confirm my own observations. I have taken one set of indicator diagrams, on a forging press in Paris, some of which I have published in another paper*; but for this Institute I should like to have some more diagrams before I go into print. I hope to get them within a year or so, because we have several other direct hydraulic forging presses going into operation in various European countries.

There is little published information about the maximum permissible rate of decompression. In the development of our own valves we have had some work done by the Department of Scientific and Industrial Research, with their valuable oscillograph instruments. We have actually measured the rate of decompression, and we find that we can definitely decompress at a mean rate of 3000 h.p. with oil, without difficulty or damage. This was on a 1000-ton press.

There is a very distinct difference between water and oil, e.g. the cavitation damage with oil is much less than with water. Cavitation damage with water is really very serious, owing to a combination of corrosion, erosion, and cavitation. On the other hand, it has been proved in the laboratory that cavitation damage with oil is almost negligible, which makes it possible to work at very high oil-velocities through the decompression valves.

We have not experienced any 'grit lock' due to 'closer clearances' as suggested by the authors on p. 205; we have found that closer clearances prevent grit entering the lapp, and Mr. K. J. Whiteman of the British Hydraulic Research Association has shown that this also prevents hydraulic lock.

The authors say that some high-speed pumps are not as reliable as slow-speed pumps, but it must be remembered that the slow-speed pump which may be of 600 h.p. or more, is a very large unit. If anything goes wrong the resulting breakdown is serious. But with high-speed pumps a large number (perhaps 20) will be used, so that if one or two break down there is plenty of time to overhaul them individually. Moreover, the high-speed pump is small, fairly cheap to replace, and can be sent by air to remote places so that repairs can be carried out quickly and cheaply.

The authors also mention peak loads; a high-speed pump driven by a motor at 1440 rev/min might put a serious peak load on the power line. Our experience so far is that those peak loads are not of any great moment in a steelworks, because there are other items in the plant, such as rolling mills, which take very much bigger peak loads, so that our peak loads have seemed comparatively small; I am speaking of forging presses of 1500 tons downwards. The authors are probably right in saying that there is a limitation of size so far as the direct drive is concerned at present, because sufficiently large high-speed pumps are not available to cater for very large presses. It must be borne in mind, however, that there are not many very large presses extant. The largest potential field consists of presses under 1500 tons, and it seems likely that this will be developed very greatly in the near future, particularly for special alloy steels, where the rate at which energy can be put into the metal is limited.

The metal is heated by the forging input, and if required, it can be made hotter than it was when it went into the press, but with high-speed and high-quality steels that is often undesirable. There is a definite limit to what can be done with special steels in the way of heating or cooling.

Many of the high forging speeds which are mentioned are advocated, particularly for planishing, to reduce the time the tool is in contact with the steel. There are two ways in which that time can be reduced; one is to increase the speed of penetration and the other is to reduce the time of the reversal. The latter is the better solution but it is limited by the rate of decompression.

A great deal of research still seems to be necessary to see how rapidly it is possible to get rid of energy. The British Hydro-Mechanics Research Association has done some work in this direction. The D.S.I.R. has assisted by conducting research into the rate of decompression and the rate of flow through valves, but a great deal of work has still to be done.

In the case of the 7000-ton press in Sheffield, pipeline velocity is about 10 ft/s from the pump to the press, which means that the pipe is quite large. Consequently there is at least one main cylinder volume in the pipe between the pump and the press, thus doubling the amount of energy which has to be destroyed before the press can be reversed.

On p. 205 the authors refer to energy being taken from a flywheel through a period of 40 s. This deserves explanation, because if energy is taken out of a flywheel for 40 s, then forging at 2 in./s represents a stroke of 80 in., and at 5 in./s a 200-in. stroke. Forty seconds seems rather a long time. With repeated strokes it is possible to take the energy out of the flywheel, and in between strokes it is possible to put it all back. I should like the authors' views on that. On the same page they refer to the flow as being probably streamline, but according to our own practice, I do not agree with

*"Control Valves for Direct Hydraulic Presses," *Proc. Inst. Mech. Eng.*, 1953, vol. 1B, pp. 420–427.

this. We use comparatively thin oil (20–50cS) and fairly high pipe velocities (about 30 ft/s). There is a very great advantage in high velocity, quite apart from reducing the size of the pipe, in that there is not so much liquid under compression, and that affects the amount of energy which must be disposed of at the end of the stroke.

Pressure surges must also be considered when operating at high pipe velocities. The answer is what Mr. Elkan has described as a negative one, namely, to have no pipes but to mount the valve right on the press, as we have done in our latest designs, and avoid the long pipeline. That has certain definite advantages, and it has been effective. In the paper, the authors deprecate complication in valves and equipment. We all drive motor cars, and they are very complicated, but provided they do not go wrong, we do not complain of the complication. We live in a complicated age, and it may be a long time before we get back to the simplicity of being able to hit something with a hammer to make it work.

Mr. **B. E. P. Lavender** (Stein and Atkinson Ltd.): On p. 207, the authors refer to the servo control of large valves, and I should like to touch on this in relation to its effect on water hammer. It would appear that if we can provide the means of servo control incorporating the proper type of valve spool to pilot some of the pressure off before the porting is open, then much could be done to stop the thump or shudder resulting from high-speed columns of water in motion which is evident when we open up high-pressure water ranges. In oil or water hydraulic circuits this can be accomplished by suitably gashing the spools of control valves in such a manner that when they cross their porting positions a gradual levelling off of the pressure is achieved and, what is more important, such is the precision of servo control that the previous crude methods whereby the valve was either open or shut are avoided.

I should also like to refer to the possibilities, especially on the smaller ranges of presses, of applying oil hydraulics. It is orthodox to employ pre-filling for the main rams and use auxiliary rams for the rapid closing and opening as opposed to large direct pumping equipment involving great expense and large input horse-powers. I have in mind not so much large forging presses but smaller ranges of presses. This point is worthy of note of exactly what can be done with these unloading hydraulic circuits giving the distinct advantage of rapid motions and high tonnages with very low horse-power inputs.

Mr. **Frith:** With reference to the pumps which I mentioned earlier, Mr. Elkan said that he did not see why water could not be used. Water could be used; the choice of oil was unusual in that oil was used with a type of pump which normally employs water.

To refer to Dr. Bramley's remarks about position control, the normal servo gives velocity control but not position control. If the position control which is required is a definite distance between the top and bottom tools of the press, it is quite easy to arrange; but with the normal forging press there is one other factor to consider. Usually part of the stroke is done as a pre-filling stroke, then pressure is applied and the forging stroke is carried out. The point at which pressure is applied can vary with every pass of the forging through the press, and the position control must operate at that point, which is a variable point.

The steam–hydraulic intensifier press had in the intensifier a member which moved only when the press was under pressure and not during the idle stroke. It could be used admirably to operate the feed-back gear back to the valves, and in a rough and ready way position control was given, inasmuch as when the operator ceased to move the handle, the press ceased to move, subject to the expansion of steam. Such a device could be repeated, but it would be a little more complicated with the normal pump and accumulator or direct pump press.

In Appendix III there is a very interesting note about water hammer effects, in which it is shown that the excess pressure rise in the pipeline due to water hammer in lb/in² can represent 63·8 times the velocity of the moving water in ft/s before the start of complete valve closure. Goodman, in *Mechanics Applied to Engineering*, gives a figure of 63·5. Taking a figure of 60 as approximately correct, then with a velocity of 30 ft/s, if the valve was shut practically instantaneously there would be a pressure rise of 1800 lb/in² above the nominal line pressure. From the point of view of the pipe-line the relative increase is less at high pressure than at low, because this build-up is irrespective of pressure and solely a function of velocity; and 1800 lb/in² represents far less when added to a pressure of 4500 lb/in² than when added to a pressure of 1500 lb/in² and can come within the normal overall capacity of the pipe, whereas with low pressure it can virtually double the pressure and so cause trouble. Many of the difficulties with pipes and systems generally may have been due to lack of information on this point.

As the authors show, the velocity of 30–40 ft/s through pipes and valves is the ideal to aim at, and anyone who uses a velocity of 70–80 ft/s is asking for trouble.

Mr. **Benson:** I agree with Mr. Towler that press performance is not indicated by penetration speeds alone. To assess the performance of a press, pressure/time and travel/time diagrams are needed. These record the time taken to build up forging pressure; the maintenance of pressure during penetration, the time of decompression, the time of lifting, and the time in the 'up' position taken for manipulation. This last item is independent of the press and will make clear how a good press can often be spoilt by bad manipulation, either through unsuitable tools and methods, or slowness of the plant available.

It may be possible, with such diagrams, to see the difference between one press driver and another, where one driver slows the press down more than another, in order not to over run the 'size' mark on the position scale, a trouble we hope may be obviated by position control.

Regarding position control, I would suggest to Dr. Bramley that the object to be sought first by this innovation is mainly to keep the press moving at maximum speed and to stop it with reasonable accuracy at a desired point. This desired point must in general forging work be varied from stroke to stroke of the press. The simplest examples, e.g. tapered ingots, forgings with steps or tapers, rectangular forgings, and even the limitation of press travel imposed by the danger of overlaps, all require a constant variation of press travel and make it difficult to visualize for some time the success of complete preset programmes of press movements for anything more than cogging straight, round, or square bars.

Regarding overloading of presses, I quite agree with the limits suggested in the paper, but as a forge operator I ask how often do we limit ourselves to the sizes given—to 10-ton ingots of 29 in. mean dia. with a 1000-ton press, for example. The figures do not even give a full measure of the overload if they are exceeded, because they assume normal forging temperature and do not allow for cold heats, wide thin slabs, and extra loads

caused by offset forging with a broad bottom tool and a narrow top tool.

The bad effect of overloading cannot be too strongly stressed. If a high-speed press is installed capable of the very fast penetration of 10 in./s, and the press is overloaded, two things happen: (*a*) If the press is operated by air–hydraulic accumulator it will be in the stalled condition and will be exerting its designed total pressure and penetrating only at a speed such that the resistance is equal to this total pressure; comparatively little overload is sufficient to reduce the penetration from a high speed to a creep. (*b*) If a direct pump-driven press, with pumps working at constant speed, is similarly overloaded, pressure will also rise to the maximum and a relief valve must operate somewhere in the circuit to prevent a disastrous overload. Whilst this relief valve is open, designed penetrations are not being obtained.

Overloading, therefore, causes dangers of overstressing the plant, while it is obviously wasteful to install a high speed press and then cause it to work at lower speeds, by overloading it.

Release of load sometimes happens during forging, e.g. when something slips under the press, etc. Experience has shown that with a steam–hydraulic intensifier with steam lifting, if anything happens at all it happens in the intensifier, and there is a sudden shock due to that release; but with a pump-driven press, having a constant hydraulic pressure in the lifting cylinder during the stroke, a sudden release of energy causes the press to drop and build up very high pressure in the pipeline to the lifting cylinder. In our experience bursts have occurred in these pipelines. Are there any developments which will avoid this danger?

In long pipe lines, with a total pressure of 16 atm the loss in a 90-ft pipeline was 0·6 atm. If the pipe-line were five times that length (450 ft), the loss would presumably be in proportion and would be about 3 atm. This would be an acceptable loss if a press were built 450 ft from the accumulator pumping station, but that would involve a long column of water stopping and starting up to 100 times a minute. Would it be satisfactory?

Dr. **Bramley:** From one or two things said this morning, with regard to eccentric loadings in particular, I think that perhaps the mathematics are not as complete as they might be. Have any forge manufacturers or users at any time put strain gauges on their forge housings to verify whether the design criteria which are being followed are in fact true? If this is done they may have a surprise. I do not think it would be difficult to do, and it would give some extremely useful information.

Mr. Elkan has mentioned that he already has some extrusion presses which work on position control. There are a number of presses which work on a rudimentary form of position control, but those with which I am familiar have a very low order of accuracy. Is there any quantitative information available on the sort of accuracy which can be obtained, e.g. on hydraulic control, with an order of accuracy better than 1%?

Two or three speakers have suggested that remote position control may not be sufficiently flexible, but perhaps they had pre-setting programmes in mind. In a pre-set programme control, which is a development of the ordinary position control, a series of stops are set, and every time the operator presses a button the various operations are effected in sequence, one after the other. That does involve a certain amount of inflexibility. At B.I.S.R.A. it has been realized for some time that this is a disadvantage of position control, and we know of several developments of position control which have failed because of this lack of flexibility. Therefore, we have concentrated on building a flexible control. I do not now refer to hydraulic control, but I think that what can be done electrically can be done hydraulically and by other means, so that my remarks will probably apply to hydraulics.

There is a 50-h.p. motor mock-up in the B.I.S.R.A. laboratory at Battersea which is under remote position control. It has a completely flexible arrangement and an inflexible arrangement incorporated side by side. There is a ratchet wheel which can be pulled round by means of a lever in steps of about 0·01 of a turn, and it may be pulled round 1–12 steps at will. It is for a screw-down, and if it is set at 8 steps this means that each time the lever is pulled there are 2 in. of screw-down. If the ingot is too hot, a knob may be turned to alter it to 7 or 9 or whatever is thought necessary. In addition, there is a hand-wheel on it, and by this means the control can be set to any analogue dimension. It need not have anything to do with the ratchet; if the control is too inflexible with the use of the ratchet, the ratchet is abandoned and the hand-wheel used. The ratchet is completely independent of the hand-wheel, and vice versa.

These 'higher quality controls,' as they may be called, have all the advantages of old controls and a good deal more. In servomechanism theory, controls are classified according to their order. It is fair to say that the last war brought forward a new technology in servo control, simply because the old controls were not good enough. Over the last decade or so, control systems have been produced of a far higher order of control than ever before. But this technology has not been applied in the steel industry to the extent it should be. Here is a vast new field which so far has been used only for warfare, but which should have a very useful application in heavy industry in the country generally. I do not think that it is a valid argument to say that these high order controls are going to be inflexible. Although there are exceptions, it is surely reasonable to say that most of the things which can be done with the old, crude controls can be done a good deal better with the new, high quality feedback controls.

We have been told that what is required of position control is a control which will move the press head forward so many inches after it has touched the piece. That is not at all a difficult requirement, but I am not sure that it is what is really needed. Remote position control should allow any workpiece to be worked to a finished dimension between the press head and the anvil. If in the early stages only a certain travel is required, that can be effected. It is not very important if this cannot be effected quite as accurately as working between the anvil and the press head, because the final measurement with remote position control will be the finishing dimension, and it should be possible to finish that to a high order of accuracy.

I agree with Mr. Benson that more attention should be paid to indicator diagrams. They are really a kind of illustration of the steady state, in a fairly flexible manner of defining it. However, is enough attention being paid to the transient response of the forge? These big pieces of machinery have their own periods of vibration. It was mentioned this morning that everything possible is done to avoid the natural periodicity of the forge, for obvious reasons. It seems to me that in these days, when high order control systems are being designed, steps should be taken to obtain the transient response which is required, rather than to put up with what transient response is obtained, and more attention should be paid to the equations governing the transient response of these heavy forges.

Mr. **W. G. James** (James Walker and Co., Ltd.): Referring to packing, the single ring with lips no doubt has its place in industry but forging presses present a specialized application. A single U-ring offers one chance only of sealing a fluid and, therefore, it is necessary for it to have comparatively long thin lips to accommodate ram deflections and to seal under low-pressure conditions. On forging presses, packing wear rate is high and it is not long before such a seal is useless. Furthermore, extrusion of the packing takes place in the clearance between gland bush and ram. The extruded material comes from the base of the U-ring, weakening it at this point, and under shock loading it is only a matter of time before rupture occurs.

In a multiple-ring set, the rings are much more robust and the lips do not have to be so long, as there are more of them. It is not simply the first ring which does the sealing ; they all contribute, the first doing the major portion, of course. Each ring helps to prevent extrusion of the preceding ring and the comparatively large mass of material under the lips swells in time, to some extent making up for wear.

Mr. **T. C. Lindop** (Loewy Engineering Co., Ltd.): In reply to Dr. Bramley's colleagues' remarks on the mathematics in this paper, I say we are not mathematicians but engineers. It is only to get a much more accurate assessment of the stresses in the press columns that more modern methods of calculation have been used.

The Moment Distribution method used in this paper is now fairly well known to structural designers. It can be carried on to any degree of accuracy by increasing the number of operations which are only of simple arithmetic.

This is what we engineers want, because we have no time for long calculations and very few mathematicians that come into the design office remain skilled in the art after 12 months.

By using method (2) of the paper, we can obtain in just over an hour a good idea of the maximum stresses.

If the mathematicians can give us more accurate figures in the same time, by all means let us know their method, but they must realize that time to do these calculations is to be the minimum consistent with the accuracy of $\pm$ 10% on the maximum stresses.

When we use these methods we are all the time designing the machine and the mathematics is used as a tool to give results on the safe side. If we have a flange 14 in. wide and we think the stress across this flange varies, then we do not use 14 in. in the calculations. Where these stresses have been ascertained by strain gauges, the result has been that we were agreeably surprised to find actual stresses lower than those given in our calculations.

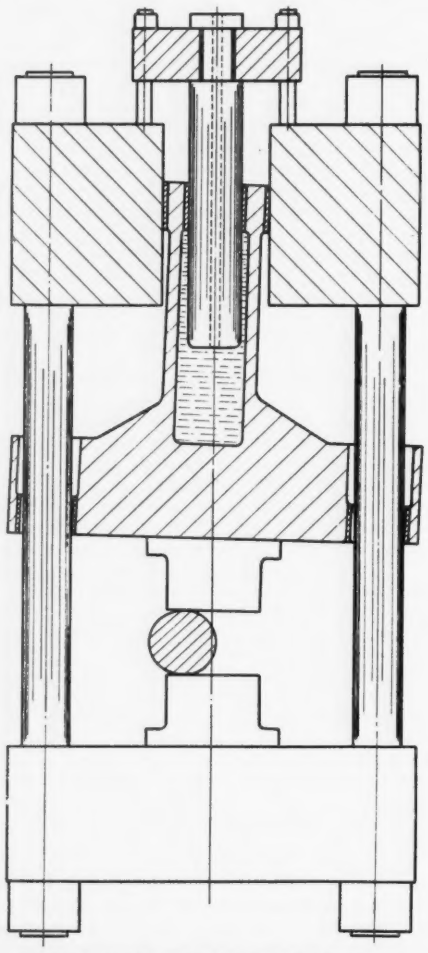


Fig. H—Gland packing affected by wear

Mr. **F. S. Salter** (Loewy Engineering Co., Ltd.): I shall amplify what has been said about the use of a central cylinder for the dual purpose of guiding and for producing thrust. It is recognized that taking side thrust on a ram is bad practice and inevitably gives trouble, but in the presses described by the authors, there is a little danger of side thrust being transmitted to the hydraulic ram. A central guide stalk rigidly rooted in the moving crosshead is provided. The top of the stalk is bushed and slides in a guide way. The stalk is hollow, and also serves as the central cylinder.

It is to be noted that the gland bush travels with the guide stalk bush and slight angular movements of the stalk are possible within the limits allowed by the normal running clearances. The ram is not rooted to its abutment above the press entablature, and can move sideways freely to adapt itself to the alignment taken by the guide stalk. In Fig. *H*, in which the effect is much exaggerated, the movement due to eventual wear is shown to affect the gland packing to a very slight degree.

Reference has been made to avoiding hydraulic shock caused by abrupt closure of piston valves by gashing the spools, thus allowing a small flow before the spool uncovers the port. The modification of the conventional mitre valve shown in Fig. 5*b* of the authors' paper has the effect of reducing the flow almost to nothing when the mitre valve is nearly closed. By this means a much improved characteristic of opening is achieved, reducing shock and giving finer control. What is more important, however, is that energy due to the high velocity through the nearly closed valve is absorbed, not by impingment of the water on metallic surfaces, with consequent wear but by turbulence within the fluid itself.

Another question arose about the type of press in which the guiding is done entirely within the top crosshead. It was asked " where does the bending moment go to? " I think that the answer is that no bending moment is created. The press may be considered in a state of static strain with the full pressure exerted on the main cylinder, and the work piece placed between the anvils but set a little to one side, whereby the load imposed on the tie rods is unequal from side to side as

in Fig. *1*. Thus, only vertical forces are acting. No lateral forces are resisted by the columns due to the eccentric condition of loading.

We have experienced a few breakages of hydraulic cylinders, not necessarily of our own make. There have also been cases of faulty castings. I would hasten to point out that these were not due to bad design, such as abrupt changes in section. Instances have occurred of broken cylinders which appear to be perfectly proportioned, proving that it is not always deficiencies in the cylinder proportions which cause the breakage. A weak crosshead which gives excessive deflection can concentrate the load on certain portions of the cylinder flanges, with consequent breakage. Cases have occurred where one or two replacement cylinders have been fitted before the true cause of the trouble—a weak supporting crosshead—has been discovered.

Mr. **Melville:** The subject of hydraulic pipes has not yet been raised in the discussion. A recent fatal accident has led us to make a survey of hydraulic piping and the results have been most illuminating. The number of cracked pipes found runs into double figures and all these pipes would have burst eventually if left in service. The cracks invariably occurred at the neutral axes of bends and were found to be due to corrosion fatigue under the stress concentration caused by the distortion of the pipes from the circular form. We have been able to evaluate these stresses approximately by calculation, and have found that 18,000 lb/in^2 on the maximum shear strain energy criterion is the maximum which can be used safely in pipes of 23-ton steel. To limit the stresses to this figure, we are changing to heavier pipes and restricting the degree of flattening at bends to a definite figure. Hydraulic plant manufacturers appear to pay little attention to this matter and there must be many pipes in this country which may burst any day, possibly with fatal results.

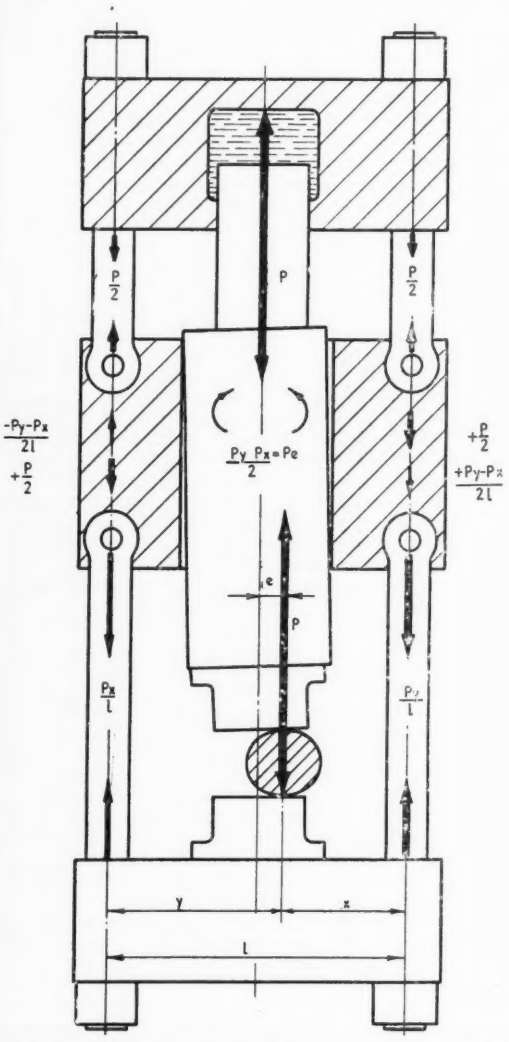


Fig. I—Unequal load on tie rods by workpiece off-set between anvils

AUTHORS' REPLY

Mr. **Elkan:** Mr. Bennett has raised the question o the percentage of soluble oil which is required in a closed water system. The figure of 2% to 3% stated in the paper should have been given as 1 to 1¼%, the normal recommended figure, and I am grateful to Mr. Bennett for drawing attention to this point.

We were interested in Mr. Bennett's figures in connection with packing life, for it is exactly this interchange of experience which makes meetings of this kind valuable.

I would like to deal next with Mr. Bennett's point on the exhausting of pressure water directly into an air-loaded reservoir, or into an overhead supply tank. It is agreed that the energy must be dissipated; some of the energy of the press is dissipated partially in internal vibration, i.e. the columns 'pull' themselves together and dissipate much strain energy. Some of the strain energy of the cross members, and most of the liquid energy is generally destroyed in the unloading valve which may be situated in the main outlet valves or in other convenient locations. We have not used the expedient indicated by Mr. Bennett, but we have had no trouble with the methods of unloading which we have used, nor with our special unloading valves. One way of destroying energy is by letting a force move through a certain distance, e.g. a spring pushed through a certain distance will absorb mechanical energy, and we can then allow it to extend back to its free unstrained position at a slower rate than that at which it was compressed. A very effective form of spring is the air cushion; this will absorb energy at a very high rate and then allow its release at any controlled slower rate.

It may be a negative way of giving a positive answer to say that by the expedients we use we have encountered no troubles. There may be other effective means of dissipating energy, but we have certainly had no undue wear or erosion on pilot valves or other pressure unloading devices adopted, and which have sometimes had to deal with up to 120 sudden pressure releases per minute, e.g. when planishing.

Mr. Pell's figure for the packing life experienced on his plant is certainly encouraging; one point that may have escaped the previous discussion of this aspect is that factors such as the degree of cleanliness of the atmosphere, and the water temperature of the circuit will also have a marked effect on the life of packings.

In reply to Mr. Towler's remarks, I would state that the talk of higher speeds of forging is no longer a matter of conjecture. In recent times there has been a steadily increasing demand by forging operators for higher penetration and auxiliary speeds, and the press manufacturer and designer must meet it. The press user now

wants high speeds of operation but at the same time he wants to squeeze the work at something very near the rated tonnage of the press, and it is necessary to design the circuit so that the pressure is available at the press, coupled with the required high speeds of working.

With the water-operated pump and valve equipment supplied with hundreds of installations, we have not encountered any great cavitation troubles.

On the possibility of using very high velocities through decompression valves, there has certainly been no difficulty with the valves we have used with water. In general, when considering velocities through valves, very much higher speeds can be tolerated through water valves than through oil valves, and both experience and theory indicate that permissible oil velocities are generally in the region of half those that can be used with water. There is no doubt that oil results in fewer corrosion tendencies. The particular oil used in the equipment mentioned by Mr. Towler is very good in that it is light and of very low viscosity, but even with this oil one cannot use as high velocities as with water. The friction effects are pronounced, and this implies heating and the problem of heat dissipation; also oil is far less suited to heat dissipation than water. We agree that higher forging speeds are required for planishing to reduce the time the tool is in contact with steel, and it is highly desirable to reduce the time of reversal. The correct solution is to have both high forging speeds as well as the shortest possible reversal times, and in this connection the latest high-speed accumulator-driven forging presses equipped with modern servo control have been capable of 100–120 pressure reversals per minute.

The 40-s time period referred to, during which it might be necessary to withdraw energy at a steady rate from a flywheel, was mentioned as an extreme case of a directly driven press, which has hitherto nearly always worked with penetration speeds of not more than 2 in./s, and as Mr. Towler states, this implies an 80-in. stroke. Our whole point is that there is a limitation, for it is not possible to take the energy out of a flywheel over too long a period. Electrical experts will be able to tell us more about the economical period of time over which energy can be taken from a flywheel, but without involving the use of very expensive equipment there is a limit.

The statement that "in some oil circuits the pipeline flow might be streamline and not turbulent" is emphasized for when using even the comparatively thin oil as mentioned by Mr. Towler, e.g. 50cS kinematic viscosity, and a pipe velocity of 30 ft/s, it is seen by substitution in the formula on p. 211 that streamline flow does in fact exist for all pipe bore sizes of 0·43 in. and less.

It was interesting to hear Mr. Towler say that the present limit for oil drive application to forging presses is somewhere around the 1500-ton press power; this corresponds to our conclusions in the present state of development of oil drive. It is always theoretically possible, of course, to put in a tremendous number of pump units, e.g. 20, 30, or even 40, but Mr. Towler will be the first to agree that, not only from the sheer geographical space requirement, but also from the aspect of initial cost, this is not a practical solution. Moreover, if it is going to require as many pump units as that, one may as well have a reservoir, i.e. an accumulator, and fill this up at a steady rate during the mean time period, and have the fluid volume available at any desirable rate for the peak demand period.

As for having no pipes, where with small presses it is possible to put the pumps on top of the press, it is a great advantage. To cut down pipelines, quite apart from cutting down expense, is certainly better for efficiency of transmission. With presses in the range above 1000 or 1500 tons, however, it is not possible to put all the pumping equipment on the top of a press. We showed this morning a press where all the oil pumps were on a platform on the top of the press, which in this instance was a very neat arrangement.

However, there is nothing wrong with long pipelines as long as the velocities are kept low. It very important to keep the velocities down; high velocities result in high friction losses, which means inefficiency and using up the pressure in the pipe lines instead of in the press, and they can lead to water-hammer effects. From these considerations there is everything against using too high velocities. If high working pressures can be used, as Mr. Frith said this morning, and cut down the moving volume, then by all means this should be done, but the velocities should be kept down.

The modern motor car, I agree, is a very complicated piece of mechanism, which we cannot just hit with a hammer if it will not go, but we must compromise somewhere between too much complication for equipment that has to work in forging and extrusion plant, and the cruder methods which were once used. One must not lose sight of the importance of simplicity and accessibility; these help maintenance and enable sources of trouble to be quickly remedied.

As Mr. Benson and Mr. Towler state, there is a great need for indicator diagrams. A more thorough study of such diagrams than has hitherto been possible will be very valuable. However, it is necessary to be careful, for unless one has a complete range of indicator readings over the whole and varied field of forging, one may very easily get a wrong impression, and the non-specialist may draw wrong conclusions. What is applicable to a die-forging press, or to a free-forging press working on very light ingots, may not be applicable to another case in which deep bites are taken under totally different conditions. In other words it will be important not to draw conclusions from one set of indicator readings and make these applicable to all presses under all conditions.

As regards Mr. Benson's point concerning the possible overloading of presses, conditions inevitably appear to arise when a press is called upon occasionally to handle ingots for which it was not intended, or to work material under conditions which will imply the stalling of the press. However, apart from not doing the work efficiently, the overloading of a hydraulic press is in no way critical as no mechanical damage can result, a situation which does not apply to mechanical presses.

Mr. Benson mentioned the danger of intensification when having constant hydraulic pressure on the return cylinders when on direct pump drive, and asks whether there have been any developments to avoid this danger. One means of minimizing the danger is to have fairly large-bore connections between pipe and cylinder as well as a generously proportioned pipeline. This may then also be inter-connected to a special shock absorber (not spring or weight-loaded); such expedients have been found to be effective. When the return cylinders are connected back to the accumulator while forging, any sudden release of energy is comfortably taken by the latter, acting in effect as a shock absorber, and intensification is avoided as long as the liquid can get away quickly, i.e. a large bore of the cylinder connection and a generous pipeline are necessary.

Referring to the friction loss in a 90-ft pipeline equivalent to 0·6 atm, it is correct that this particular loss would be about 3 atm in a 450-ft length. As for the possibility of starting and stopping such a water column a hundred times a minute, this is practicable if sufficient acceleration head is available at the accumulator station, and here, too, another expedient is available should this not be the case. This ties in with the previous

point that it will often be the most desirable solution to keep the velocities down as low as possible, though it may be desirable to have the working pressure as high as possible.

In reply to Dr. Bramley, we have put strain gauges on press structures to verify design criteria which were being followed, and the results obtained were very satisfactory. As regards the quantitative information on position control with an order of accuracy of something better than 1%, this is not yet available. There is always a time lag between actuating the control mechanism and stopping the movement, whether it be done hydraulically or electrically, and it may be that 1% is too fine when one considers that there is the compressibility of the fluid to be taken into account. One may have one press movement with a resistance of 150 atm, and the next one with a resistance equivalent to 300 atm in the main press cylinder, and thus the very compressibility of the fluid would render impossible the achievement of such a fine position stop.

I was very interested to hear Mr. James' remarks on packings; experience seems to vary and Mr. Pell's figure for the life of his packing is extremely encouraging.

Mr. Melville raised the question of hydraulic piping and mentioned that 18,000 lb/in² on the maximum shear strain energy criterion as being the maximum that can be used safely in pipes of 23-tons/in² steel. No doubt this figure can be exceeded by using steels of slightly higher strengths. Apart from other factors, excessive velocities may here again be the cause of some troubles. The effect of sudden valve closure, sometimes thousands of times a day, can result in pressure surges in the longer pipe lengths if the velocities are high, and water hammer exists whether audible or not. Rarely, if ever, have circuits been designed in the past to allow for this, and apart from the ordinary hoop and radial stresses, such water hammer stresses are superimposed on the latter and may well have no small contributory effect on pipe failures.

I hope that it will not be suggested that we have favoured either accumulator drive or direct drive, oil or water, for we have a completely open mind on this subject. The firm with which we are associated has more than 90 major press units working on oil drive in different fields of application, and there are of course hundreds of air–hydraulic accumulator installations. We have, therefore, no reason to be biased in favour of either one or other method of drive. In industry it is necessary to examine each application objectively if good engineering is to prevail.

Mr. **J. T. Lewis** (Loewy Engineering Co. Ltd.): I have made copious notes on the many and interesting points that have been made during the discussion to-day, but as Mr. Elkan has dealt with most of these, there are only one or two small remaining points I would like to raise.

Mr. Benson this morning mentioned that the presses shown had no dial to indicate the stroke, but I hasten to reassure him that we do, of course, fit indicator gear to all forging presses. In some cases these are of the dial type, and in others just the plain vertical scale type, depending upon the particular wishes of the press operators.

On one of the slides shown this morning, no indicator was visible as the photograph was taken in the very early days of erection and testing, before this gear was fitted. However, I have not found it unusual to see the forge foreman coming along with a piece of chalk and making a mark on the vertical scale at which the driver is to stop, even though a dial type indicator had been fitted.

In connection with Mr. Bennett's comment regarding the soluble oil content of the pressure water system, we agree that the content should be usually 1–1¼%, depending upon the hardness of the water. If the oil content exceeds this amount troubles may arise, for the oil does not emulsify with the water and moves about the system in the form of free globules associating with dirt particles etc. Eventually, certain scum formations result which may stick to surfaces. Strictly speaking, the oil should not be added to the water, but rather, an emulsion should be made separately first by adding water to a measured quantity of oil, which results in complete emulsification and uniform distribution, and this is then added to the main water system.

I was glad to hear Mr. James' answer concerning multi-ring packings, and we agree with him that the first ring does not usually effect complete sealing. We have co-operated very closely with the manufacturer of packings over a period of many years and the products as marketed to-day are very good and reliable, as proved by Mr. Pell's figures of the packing life already obtained with modern packings.

Mr. Melville appears to have had very bad experiences with occasional cylinder breakages on some of his presses. With adequate care in detail design and a suitable choice of material, forging press cylinders should give trouble-free service for many years.

Regarding the pipe troubles Mr. Melville has encountered, care certainly is necessary, and we endeavour to take as many precautions at the bends as possible. Not only do such precautions extend to the limitation of the degree of curvature at such bends, but efforts are also made to ensure that minimum wall thicknesses laid down are adhered to, and as many expedients as possible are adopted to avoid local thinning and ovality.

The authors regretted that the paper did not produce more comments on the suggested method of calculating water hammer effects in high pressure systems, or comparative data and criticism on the valve loss factors put forward.

It is hoped that research associations will in time produce more information for users of forging presses. It is realized that industry must present its questions and state its problems to them, but whereas there is rightly a considerable emphasis on fundamental research, which is the vital basis on which to build, there is not as yet sufficient emphasis on that form of research necessary to answer questions on direct application that industry asks, and that so often remain unanswered.

CORRESPONDENCE

Mr. **Salter** wrote: It has been suggested that forgemasters are perhaps a little conservative and any innovations of automatic or partial automatic methods of control for forging presses, might receive a doubtful welcome in some quarters. However, Mr. Benson had suggested that present day controls, even when made very sensitive, leave much to be desired and the accuracy of the product is entirely dependent upon the skill of the driver. Many people consider that modern tendencies towards automation have a very serious effect in removing pride of achievement and exercise of skill in industry. However, Dr. Bramley had made it clear that improvements in controls should not be of such a nature that skill and judgment are no longer necessary and the improvements should aim at removing the purely mechanical part of the operation, leaving the individual free to expend all his efforts in duties which cannot be done by purely mechanical means. Muscular effort is no longer needed since accurate and sensitive control can now be provided by suitable servo-operated valves. The improved form of hydraulic press control

mentioned by Dr. Bramley is under consideration and developments are stimulated by his remarks and by the comments of Mr. Benson. It is only necessary to take a feed-back from the press movement to a motion representing the desired press travel differentially linked with the control valve to give a remote positional control.

A patented arrangement of control system developed by the writer's firm would take the following form. The operator would move a pointer along a scale situated on his control desk. The scale would represent the press stroke. Readily adjustable stops would be pre-set on the scale, the upper stop denoting a limit of upward movement, the lower stop denoting the size to which the forging is to be reduced. The operator would move the pointer according to the way he wishes the press head to move. This remote positional control gear accurately controls the press head so that it makes the required movement. The mechanism would be arranged so that the operator cannot move the handle quicker than the press head can follow the command. From the users' point of view the equipment would appear very simple. It only remains for the engineer to develop the unseen parts to the requisite efficiency and reliability. It is not expected that accurate sizing may be achieved without making allowance for elasticity of the press parts where deflection varies with the load.

It would be amusing to hear the comments of a press driver of the old school when confronted with such equipment. However, similar situations have occurred before and such skilled operators are known to occupy comfortable seats and are controlling with precision and rapidity large forging presses with the exercise of great skill and experience but entirely without fatigue or regrets for the passing of out-dated methods. Developments of this kind can be introduced by degrees without immediately throwing away existing methods of control.

Remote positional control applied to the turning gear would, no doubt, be useful although very excellent regularity and roundness can already be demonstrated on the quick-acting presses mentioned in the authors' paper. The quick forging and planishing rate is such that the turning gear is rotating steadily at low speed while the press makes rapid planishing strokes giving a circular forging with the appearance of a polished, rolled surface.

Forgemasters like to employ the methods they have found satisfactory in the past, knowing that anything novel but lacking essential robustness will be continually troublesome. Nevertheless, improvements seem to be long overdue in the method of positioning and fixing tools.

Mr. Bennett referred to the use of the dovetail employing bearing surfaces at different levels which is indeed unsatisfactory, and although common in this country it is not often seen on continental designs. However, a method has been put forward of gripping anvils where the jaws of the dovetail are closed sideways by hydraulically operated wedges, thus locking the anvil firmly against a single broad bearing surface. Tools could thus be changed rapidly during a heat by making the best use of fast moving sliding tables.

Mr. Frith and others made reference to sudden release of energy in a forging press. This could occur accidentally when cutting forgings with the 'knife.' The practice of pressing a comparatively shallow knife through a deep forging by a second distance piece held on the end of a long bar is dangerous if not done with great care. However, very little power is developed in these operations. The main danger occurred in the past with steam–hydraulic presses in which the power was controlled by admitting and cutting off steam to a large cylinder operating the intensifier. Although the hydraulic circuit is short, steam admitted at pressure to the cylinder had considerable expansive energy. After sufficient pressure has been applied to start the cutting stroke, it was not possible immediately to stop the movement of the press head by cutting off the steam, although with care an operator could prevent sudden release of energy.

The leaping of a press from its foundations is a very rare occurrence. Yet it is necessary to cater for accidental release of the strain energy in the columns, the crossheads, the compressed water in the cylinders, and in the cylinder walls. As the accelerating forces acting on the heavy parts have a value of many times their weight, it is no use attempting to bolt the press rigidly to the foundations to prevent the tendency of the two masses being accelerated towards their common centre by the elastic energy of the press parts. Such bolts would require to deal with forces equal to the power of the press at the moment of energy release. Foundation bolts of reasonable diameter can be used provided they are resilient through generous length. In special cases, where very long foundation bolts cannot be accommodated, it is possible to employ very stiff springs with the foundation bolts. The upper crosshead is not rigidly positioned against downward movement with respect to the main columns, but it is supported on very stiff springs and tie bars which also exhibit some resilience. It is usual to allow for the press power being suddenly released at one third of its maximum value.

Opinions seem to be equally divided among designers of modern presses, on the relative merits of employing either back nuts or well-secured columns without back nuts. For machines not subjected to much eccentric loading, the back nut is a very convenient means of locating the opposed crossheads in proper alignment without demanding too much accuracy of machining. A considerable rigidity is given by the friction effect of proper pre-stressing and by the width of the base exhibited by nuts of normal proportions.

Until recent years, no satisfactory method of locating the column laterally within the crosshead was in common use. There is a method of securing a column much smaller in diameter than the socket in which it is fitting by a means of segmental wedges. This method was originally applied to columns employing back nuts but has since been applied to forging presses working without back nuts. It is appreciated that axial movement is taking place between the column and the crosshead all the time the load is changing. Such wedges must be of long-wearing material and must be properly lubricated and capable of adjustment to take up wear if the rooting of the column is to remain rigid and free from play.

A forging press is essentially a device for squeezing hot metal to the desired shape. It is not a structure that must exhibit rigidity as an essential characteristic. It is indeed sometimes useful if the press can show an excessive amount of sway when it is being misused by applying unnecessary eccentric loading. As Mr. Frith remarked, sway is not a nuisance in itself although it could be bad for the pipe joints. A press which may appear rigid is not necessarily stronger than a press which appears to be flexible. It is important that the more slender parts such as the columns should have a substantially uniform cross-section without abrupt changes in stress, and this condition is not met by the use of shouldered columns. The columns must flex, taking up the positions determined by deflections of the

crossheads. These deflections are causing bending moments at the root of each column. At these points where the stress is high, it is desirable that there is uniform diameter.

Mr. Pell had mentioned certain troubles with the two recently-installed presses. While the performance in general had been excellent, some trouble occurred with the errosion of valves. This was due to the high speed of operation and to generously proportioned valves being used at low openings.

Mr. Pell described experiments to avoid erosion due to impingement of high-velocity water on the valve surfaces. One solution is given by the mitre valve having an extension piece causing the high velocity to take place on leaving the valve, such velocity being dissipated in the water chamber itself.

Mr. Bennett suggested that back nuts might be employed having conical surfaces engaging with conical seatings in the crossheads which would give greatly improved rigidity of rooting of the columns within the crosshead. This construction is attractive but presents difficulties in machining since the axes of the column bores must match exactly with the opposite crosshead. Similar ideas have been employed in the past with shouldered columns, where the machining difficulties were even greater since not only must the holes in the crosshead be exactly matched but the length over the coned portions of the columns must also be exactly matched with the distance between the conical seatings in the crossheads.

Mr. **Melville** wrote: I have not been able to understand the function of the electrical gear in the author's control diagram. Is it purely as an interlock? Whatever its purpose, I should prefer a mechanical or an all-hydraulic system, as our experience suggests that the fewer mediums used in control system the better.

The radial-type joint used in the valve shown in Fig. 5 has been undeservedly popular for many years. It is compact, cheap and trouble-free until fretting corrosion behind the fibre ring cuts into the steel housing. When this occurs, tightness can no longer be maintained. I think there is room for improvement in this detail and even at a higher cost and bulk I should prefer valves where joints were made by axially compressed rings. I have not had personal experience of them but the joints made by Dowty, which use rubber supported by metal against extrusion, might be suitable for hydraulic work and would certainly need much lower bolt loads than the orthodox metal ring.

Valve leakage in pumps and controls is a constant problem in hydraulic work, and wastes both time and power. I should like to ask the authors why the various excellent methods of hard facing now so popular for steam valves are not more used in hydraulic plant.

AUTHORS' WRITTEN REPLY

Mr. **Lewis** wrote in reply to Mr. Melville: The function of the electrical gear as shown in Fig. 4 of the paper is purely an interlock to ensure that the sliding tables cannot be used while the ejector pin may be in its 'up' position, a situation which would result in mechanical damage. Also it ensures that the moving table has been properly centred before the ejector can be used and it is not possible to use the ejector and the tables at the same time. There has been no inconvenience in using this particular electrical gear.

Of the radial-type joint shown in Fig. 5, it is true that fretting corrosion can occur behind the fibre ring, but by this time leakage and heat generation will have become evident, and it is a situation which should not generally be allowed to occur. We have had excellent results with this type of joint which swells when immersed in water, and therefore is not dependent on that absolute rigidity in machining accuracy which the use of other joints sometimes implies. We are using the Dowty type of joint referred to, for special applications on smaller pipes, with very satisfactory results.

We have not had to resort to hard facing to any large extent which may be partly because we do not have to contend with any temperature effects, and the materials as used are proving very satisfactory.

The authors hope that they have succeeded in underlining the considerable development that has taken place in recent times, whereby it is now possible by careful valve and circuit design, to have presses moving at high speeds, and yet exert a substantial part of their rated tonnage; a very recent example of which, incidentally, is a horizontal hydraulic press unit, which operates at a main ram pressing speed in excess of 40 in./s. A considerable effort is being made for a number of varying reasons to show that low pressing speeds in free forging are sufficient, or even desirable, but this is generally done by operators who have installed 'slow' plants. The proof that higher speeds of working are desirable and have come to stay is given by those operators who have recently installed modern fast-moving presses, provided that care is taken to match the handling facilities, and that adequate furnace capacity is installed.

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Iron and Steel Engineers Group

The Thirty-first Meeting of the Iron and Steel Engineers Group will be held in South Wales on Thursday and Friday, 4th and 5th October, 1956. The programme was given in the September issue of the *Journal*, p. 78.

Autumn General Meeting

The Autumn General Meeting of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on Wednesday and Thursday, 21st and 22nd November, 1956.

New Special Reports

The Russian Iron and Steel Industry

In response to an invitation by the Minister of Iron and Steel of the U.S.S.R. issued to the United Nations Economic Commission for Europe at Geneva, a British Steel Mission visited Russia in September, 1955, jointly with delegations from Belgium, France, and Sweden. The British delegation, which was led by Sir Robert Shone, C.B.E., Executive Member of the Iron and Steel Board, visited the Gigant iron ore mine and the Ugok ore concentrating and sintering plant at Krivoi Rog, the steelworks and wide strip rolling mills at Zaporojstal, the Nikopol tube rolling mills, and the Rustavi steelworks near Tbilisi. They then returned to Moscow where they visited the Central Scientific Research Institute of Ferrous Metallurgy and the Moscow Coke and By-product Plant, and finally attended a meeting at the Ministry of Iron and Steel to discuss the experience they had gained from the visit.

An account of the visit, prepared by five members of the delegation, is published as No. 57 of the Special Report series of The Iron and Steel Institute. This report describes the plants visited, and discusses the organization of steel production in the U.S.S.R. and general conditions in the iron and steel industry. Copies of the Report may be obtained from the Offices of the Institute, price 4*s*. 3*d*., including postage.

Atlas of Isothermal Transformation Diagrams of B.S. En Steels

Since the first edition of the Atlas of Isothermal Transformation Diagrams was published in 1949, there has been an increasing demand for information on the isothermal characteristics of further steels of the En series, particularly carburizing steels. Accordingly the Isothermal Transformations and Hardenability Group, under the auspices of the Thermal Treatment Committee of the British Iron and Steel Research Association, undertook the preparation of additional transformation diagrams and at the same time took the opportunity of modifying several of those previously published, in the light of clearer understanding of the significance of the experimental data on which they were based. The revised Report comprises isothermal transformation diagrams of 37 steels in the B.S. En series. Each diagram is accompanied by a data sheet which records the composition of the steel, its previous treatment, and the hardness of the transformation products obtained at various temperatures; typical end-quench hardenability curves are also given.

The Report, No. 56 in the Special Report series of the Institute, is bound in cloth with stiff board covers. Copies may be obtained from the Offices of the Institute, price 37*s*. 6*d*. (Members 25*s*.).

Symposium on Powder Metallurgy 1954

The powder metallurgy industry in the U.K. has grown at an increasing rate since the previous Symposium was held by The Iron and Steel Institute in 1947. The expansion in the manufacture of metal powders and the increasing diversity of engineering components produced from them have been coupled with considerable developments in equipment and techniques. The increase in pure and applied research work has led to a better understanding of the basic principles underlying the preparation, compaction, and sintering of metal powders.

In view of this a Committee representing The Iron and Steel Institute and the Institute of Metals was set up in 1953, which invited papers from the U.K. and abroad to cover a wide field of developments related to sintered products. It was considered advisable to include a limited number of review papers but, in general, authors were asked to place particular emphasis on research and development work which had taken place since the 1947 Symposium.

The Symposium on Powder Metallurgy was held in London on 1st and 2nd December, 1954, and the papers and discussion have now been published as No. 58 in the Institute's Special Report series. This work covers 390 pages and is divided into four sections: (i) the manufacture, properties, and testing of powders; (ii) the principles and control of compacting and sintering; (iii) the manufacture and properties of structural engineering components; and (iv) the powder metallurgy of high-melting-point materials. Name and subject indexes are included. The Report is bound in cloth with stiff board covers and is fully illustrated. Copies may be obtained from the Offices of the Institute, price £3 5*s*. 0*d*. (Members £3 5*s*. 0*d*.).

NEWS OF MEMBERS

Mr. **N. H. Bacon** has been appointed Superintendent, Ickles Departments, at Steel, Peech and Tozer.

Mr. **E. T. Gill** has taken up an appointment as Development Officer for Constructional Alloy Steels with the Development and Research Department of the Mond Nickel Co., Ltd.

Mr. **J. E. Harris** has left the Department of Industrial Metallurgy, University of Birmingham, and has taken up an appointment with the Research Laboratories, British Thomson-Houston Ltd., Rugby.

Dr. **J. E. Hilliard** has left the Massachusetts Institute of Technology and has taken up an appointment with the General Electric Research Laboratory, Schenectady, New York.

Dr. **J. P. Hugo** has been appointed Chairman of the committee charged with the formation of a Base Metals Division within the South African Institute of Mining and Metallurgy.

Mr. **L. W. Johnson** has been appointed Assistant Manager of the Development and Research Department of the Mond Nickel Co., Ltd.

Mr. **B. Needleman** has been appointed to the foundation committee of the Base Metals Division of the South African Institute of Mining and Metallurgy.

Mr. **J. H. Patchett** has been appointed a Director of Dorman, Long and Co., Ltd.

Mr. **F. W. E. Spies** has been awarded the Fox Medal of the Institute of British Foundrymen.

Dr. **B. G. Street** has been elected an Associate of the Institution of Metallurgists and has also taken up an appointment as Senior Metallurgist to Mullard Magnetic Components, Southport.

Mr. **G. N. F. Wingate** has been appointed Director and General Manager of Distington Engineering Co., Ltd.

Obituary

Mr. **Noel Douglas Ridsdale** (*elected* 1911), of Middlesbrough, on 17th July, 1956.

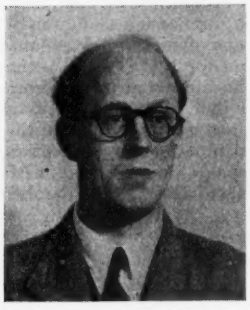
Mr. **C. E. K. Menzies,** whose death on 6th June, 1956, was recorded in the September issue of the *Journal*, had been a member of the Institute since 1934. Mr. Menzies joined Stewarts and Lloyds Ltd. in 1912 and served in the Black Watch in the First World War; in 1923 he started the firm of Nye and Menzies. He was also London representative for Fleming and Ferguson Ltd., Shipbuilders and Engineers, Paisley, for many years, becoming a Director in 1948. Mr. Menzies was 65.

CONTRIBUTORS TO THE JOURNAL

E. D. Hyam, M.A., Ph.D., A.I.M.—Senior Scientific Officer, United Kingdom Atomic Energy Authority (Industrial Group), Research and Development Branch.

Dr. Hyam was born in 1925 and was educated at Whitgift Middle School, Croydon, at King Edward VI School, Bath, and at Downing College, Cambridge. He served with the Royal Armoured Corps from 1943 to 1947 and was at Cambridge from 1947 to 1953, being awarded the degrees of M.A. and, subsequently, Ph.D. Dr. Hyam took up his present appointment in 1954.

E. Ineson, B.Sc., F.I.M.—Head of the Metallurgy (General) Divisional Laboratories, British Iron and Steel Research Association, Sheffield.



E. Ineson

J. F. Wallace

Mr. Ineson was born at Huddersfield in 1917. He was educated at Hemsworth Grammar School, near Pontefract, and at Leeds University, where he studied Fuel and Metallurgy. After graduating in 1939 he undertook research at the University for which he was awarded honours in 1940. In the same year he joined David Brown and Sons (Huddersfield) Ltd. as assistant metallurgist concerned with the control of works' processes and materials. Subsequently he became responsible for development work and, amongst other things, played a leading part in the development of gas carburizing in the U.K. He was also at that time closely concerned with the work of the Admiralty-Vickers Gearing Research Association.

Late in 1947 Mr. Ineson joined the Metallurgy (General) Division of B.I.S.R.A. Here he undertook the establishment of the Metallurgy Laboratories both in London and in Sheffield.

J. F. Wallace, Ph.D.—Lecturer in Mechanical Engineering, University of Sheffield.

Dr. Wallace graduated with Honours in Mechanical Engineering at Sheffield University in 1948 and undertook post-graduate research from 1948 to 1951. After a short period with Imperial Chemical Industries Ltd. he took over control of the family sheet metal working business and rejoined the University in 1954 as Research Assistant to Professor H. W. Swift. Since then he has worked in co-operation with B.I.S.R.A. on the development of the cup drawing test and other problems in the mechanical working of metals, obtaining his Ph.D. in 1955 for research on impact extrusion and the dynamics of drop hammer foundations.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Staff

Mr. C. N. Kington, M.B.E., has resigned his post as Group Manager of the British Iron and Steel Research Association's Sheffield Laboratories, Director of Research of the Cutlery Research Council, and Research Superintendent of the File Research Council, to become Chief Mechanical and Electrical Engineer of Husband and Company, Consulting Engineers and Architects.

Dr. J. Pearson, Assistant Director of the British Iron and Steel Research Association, took over charge of the Sheffield Laboratories on 1st September. He retains the Headship of the Steelmaking Division but has relinquished control of the Chemistry Department to Mr. E. W. Voice, Head of the Ironmaking Division. Mr. R. Mayorcas has been appointed Deputy Head of the Steelmaking Division.

Mr. J. G. Wistreich, who has been Head of the Metal Working Laboratory at Hoyle Street, has become Head of the Mechanical Working Division as Mr. W. C. F. Hessenberg, Deputy Director of B.I.S.R.A., has relinquished control of the Division so as to devote the whole of his time to his other duties. Mr. S. S. Carlisle, Head of the B.I.S.R.A. South Wales Laboratories, becomes Deputy Head of the Division.

Cutlery Research Council

Mr. E. A. Oldfield has been appointed Senior Research Officer of the Cutlery Research Council in succession to Mr. C. N. Kington.

File Research Council

Dr. J. Pearson has been appointed consultant to the File Research Council. Mr. R. H. Hancock will continue as Senior Investigator.

AFFILIATED LOCAL SOCIETIES

Lincolnshire Iron and Steel Institute

The following Officers and Council have been elected for the session 1956–57:

President: Cedric Thomas

Vice-Presidents: D. Bruce-Gardner, G. D. Elliot, O.B.E., J. L. Gaskell, T. L. Jones, I. M. Kemp, A. H. Norris, Dr. L. Reeve, J. D. Townsend, N. H. Turner, and W. T. Wilson

Hon. Secretary: Commander Ian Steel, M.V.O.

Hon. Treasurer: G. P. Elson

Council: A. Bridge, H. C. Challinor, W. Campbell-Adamson, J. Dodd, W. Geary, T. P. Lloyd, J. McLauchlan, G. Moore, W. Jackson, J. A. Peacock, C. Reid, and T. E. Shaw.

EDUCATION

City and Guilds Appeal

The City and Guilds of London Institute is launching an appeal for a stable income from industry of £50,000 a year and, in support of this appeal, has received the following message from its President, H.R.H. The Duke of Edinburgh: "The education and training of technicians, craftsmen, and operatives, who are as important as scientists and technologists, is the task which the Institute is trying to perform for Industry. . . . The Institute is unique in conception and in the position it occupies in the system of technical education in this country. It is increasingly being called upon by Industry to help train the skilled men who are so badly needed to ensure that our industries continue to compete successfully in the markets of the world. The founders are still giving their most generous and unstinting support to this work. But that is not enough any more. The Institute now needs the support of Industry if it is to meet the demands made upon it and if it is to expand its services to Industry."

Designation of Colleges of Advanced Technology

In connection with the Government's five-year plan for technical education, the Minister of Education has laid down the conditions for the designation of colleges of advanced technology. The Minister considers it important that a small number of technical colleges should develop rapidly into colleges of advanced technology, concentrating entirely on advanced studies and providing a broad range of work of the highest quality.

Postgraduate School in Physical Metallurgy—Sheffield

In view of the need of the metallurgical industries for more men with advanced scientific training, the University of Sheffield has established a Postgraduate School in Physical Metallurgy to provide special tuition in this branch of science.

Applications for admission to full-time courses (normally of one or two years' duration) are invited from:

(i) Scientists already in industry, holding a degree or equivalent qualification, who have had at least three years' experience and wish to pursue more advanced studies in physical metallurgy

(ii) Recent graduates in Physics, Chemistry, or Engineering, who wish to pursue a metallurgical career.

In certain circumstances applications will also be accepted from recent graduates in metallurgy with little or no industrial experience.

Students taking courses of one or two sessions duration may read for the degree of Master of Metallurgy or for the Diploma in Physical Metallurgy.

Preference will be given to men sponsored by their employers, but a number of senior awards are available for independent candidates each year. The fee for a full-time postgraduate course of study is £50 per annum.

Enquiries may be addressed to the Professor of Metallurgy, The University, St. George's Square, Sheffield 1. Forms of application for admission to the postgraduate school can be obtained from the Registrar, The University, Sheffield 10.

NEWS OF SCIENCE AND INDUSTRY

Steel Foundry Research

The third annual report of the British Steel Castings Research Association reports that membership of the Association now represents almost 80% of the tonnage of steel castings produced in the U.K., and includes two steel founders in the Commonwealth. Over 50 publications made available to members during the year are listed in the Report and summaries are given of the 25 research and development projects on which the Association has been engaged.

General Refractories Ltd. Tunnel Kiln

A new tunnel kiln was recently put into operation at the Worksop Plant of General Refractories Ltd. for the burning of basic refractories. It can fire at temperatures up to 1650° C and has a total overall length of 346 ft. It will hold 56 cars, each with an approximate capacity of 5 tons, giving a weekly output of 600 tons of fired bricks.

S.C.I. 75th Annual Meeting

On the occasion of the 75th Annual Meeting of the Society of Chemical Industry, The Iron and Steel Institute joined many other learned societies from all over the world on 10th July in presenting a congratulatory address.

Arc Furnace for Scottish Steel Industry

William Beardmore and Co., Ltd., Glasgow, have received approval from the Iron and Steel Board for a major reconstruction of their steel melting shop. The scheme, which will take about five years to complete, involves the replacement of the O.H. furnaces by electric-arc furnaces at an estimated cost of £1,600,000. The first stage will be to install an 'Efco' 80-ton electric furnace, which is being supplied by the Electric Furnace Co., Ltd., of Weybridge, Surrey.

National Industrial Safety Week

The National Industrial Safety Week will be held from 5th to 10th November. Its object is to encourage all workers to be "safety conscious," that is, to cultivate safe habits in working so that neither they nor their workmates are subjected to unnecessary hazards. Workers will be invited by means of special posters and other propaganda to "*Look out for booby traps*"—the collective name adopted for hazards that range from defective tools to careless behaviour. In addition, 50 or so local industrial accident prevention groups in the U.K. will be organizing special functions in connection with the Industrial Safety Campaign, in some cases with the co-operation of the local Civic Head and Chamber of Commerce.

New Thickness Gauge

Nucleonic thickness gauging by means of beta and gamma emitting isotopes is now established practice in many industries. There has, however, always existed

a gap between the upper thickness range of beta gauges and the lower thickness range of gamma gauges. In terms of steel this has been about 0·02 to 0·25 in. The gap in the past has been bridged by means of rather expensive X-ray gauges, but the new ' Bremsstrahlung ' thickness gauge, introduced by the Baldwin Instrument Co., Ltd., of Dartford, performs the same function as the X-ray gauge but at a lower cost.

Powder Metallurgy

A series of 11 lectures on Powder Metallurgy will be held at Battersea Polytechnic on consecutive Tuesday evenings, beginning on 2nd October at 7 P.M. Intending students are requested to send the fee of £1 with their name and address in block capitals to the Secretary, (Powder Metallurgy Course), Battersea Polytechnic, London, S.W.11.

International Mineral Dressing Congress—Stockholm

An International Mineral Dressing Congress is to take place at the Royal Institute of Technology, Stockholm, from 18th to 21st September, 1957, at the invitation of Svenska Gruvföreningen in association with Jernkontoret. About 25 papers will be presented and excursions are being arranged to some of the larger Swedish mines and, it is hoped, Norwegian and Finnish mines as well.

Morgan Crucible Company Centenary

In connection with the centenary of the founding of the Morgan Crucible Company Ltd., of London, N.W.11, the Company has published a well-illustrated book entitled " *Battersea Works* 1856–1956." This traces the foundation and subsequent growth of the organization and emphasizes the strong tradition of family service which has been its characteristic.

American Research on Metallic Corrosion

One of the activities of the Engineering Foundation, New York, has been to set up a Corrosion Research Council. This has the support of the American Institute of Mining, Metallurgical, and Petroleum Engineers, the Inter-society Corrosion Committee, and the Electrochemical Society.

Arc Furnaces for Carbon Steel Ingots

As part of a major expansion scheme, Round Oak Steel Works Ltd., a member of the T.I. Group of Companies, has decided to adopt electric melting furnaces to provide the increased output of steel. The first stage will include the installation of two large Birlec Lectromelt arc furnaces. This is the first time electric furnaces have been used in the U.K. for the production of tonnage steel for structural and other purposes.

Indicating Temperature Controller

A self-contained, direct-deflection instrument for indicating and controlling temperature to close accuracy over a wide range has recently been introduced by Ether Limited, of Birmingham. It is the ' Transitrol ' Type 990, and since it uses a transistor the need for thermionic valves, magnetic amplifiers, and oscillator circuits has been eliminated. The control arm, which is adjustable externally to the required temperature set-point, is fitted with a photo-sensitive transistor, optical lens, and low-level light source. A flag is connected to the pointer arm of the galvanometer, which passes freely between light source and transistor. When the desired control point is reached the light source is cut off from the transistor, thus de-energizing the control relay and shutting off the heating medium. Only a minute pointer movement is required to ' make ' and ' break ' the control relay.

New Type of Dust Collector

The Constructional Engineering Co., Ltd., of Birmingham, has introduced the ' Solivore-Titan ' cleaner, which is based on a new principle of dust collection. Conventional wet dust collectors are based on the use of baffles combined with water sprays or curtains to restrict the flow of gases and collect the heavier particles of dust from the gases before they are exhausted. These are not in general highly efficient, since it is difficult to wet particles in the sub-micron range. In the ' Solivore-Titan ' cleaner the foul gas enters a primary chamber which is heavily saturated by a special water pulverizer; the particles are collected by agglomeration or precipitation and are flushed from the chamber. The gases then expand through a special venturi pipe into a secondary chamber. The expansion lowers the temperature so that condensation can take place, the dust particles acting as nuclei. Particles as small as 0·1 μ can become wetted and easily collected.

Rolled Plate for Atomic Power Stations

The English Steel Forge and Engineering Corporation Ltd., Sheffield, are supplying 4500 tons of rolled plate for the Calder Hall and Annan atomic power stations. The plate will form part of the thermal shields which protect the concrete radiation barrier against the heat effect of the nuclear reactors.

Symposium on Nuclear Power Plant

The British Nuclear Energy Conference is arranging a symposium on "*Calder Works Nuclear Power Plant*," to be held at the Institution of Civil Engineers, Great George Street, London, S.W.1, on 22nd and 23rd November, 1956.

New Industrial Microscope

A new industrial microscope, the ' Technoscope,' manufactured by the Carl Zeiss Works of Western Germany, is finding applications in British industry. The ' Technoscope ' is a stereoscopic microscope, to which a camera may be fitted, mounted on a portable rollable stand. It has numbers of applications in surface testing.

Fuel Saving in Industry

The recent booklet "*Heat and Power Surveys: The Way to Lower Costs and Higher Productivity*," published by the National Industrial Fuel Efficiency Service, reports that from over 300 surveys the maximum fuel savings possible in any iron and steelworks is 66·9%, although the average from industry is only 27·5%.

Developments at Corby

The Iron and Steel Board has authorized Stewarts and Lloyds Ltd.'s plan for developments at Corby, which is costing £6¼ million. It will take about 10 years to complete, the first stage being the construction of 50 new coke ovens, complete with ancillary coal-preparation and by-products plants. Work will then begin on reconstructing about two-thirds of the existing 143 ovens, most of which have been operating since the works opened 23 years ago.

Fuel Efficiency Exhibition—London

Ways in which industry can save up to one-fifth of fuel costs, together with the latest information on nuclear power stations, will be demonstrated at the Fuel Efficiency Exhibition, to be held at Olympia, London, from 2nd to 10th October, 1956.

Expansion of Stanton Ironworks

The Iron and Steel Board has authorized the expenditure of about £3½ million on the development of the Stanton Works of the Stanton Ironworks Co., Ltd. An integrated ore-preparation plant will be constructed and an extensive belt conveying system will be installed for transferring prepared ore to the two blast-furnace plants.

Rolling-mill Development Plan

The first stage of a rolling-mill development plan at the Stocksbridge Works of Samuel Fox and Company Ltd. was completed in July. The plan involves the installation of three new mills for producing high-carbon precision cold-rolled strip. In addition, two existing rolling mills are being transferred to Stocksbridge from the company's Rotherfield works in Sheffield so as to consolidate stainless steel strip production in one plant.

Changes of Name and Address

The formation of EFCO-EDWARDS VACUUM METALLURGY LTD. is announced by Edwards High Vacuum Ltd., of Crawley, Sussex, and the Electric Furnace Co., Ltd., of Weybridge, Surrey.

THE INSTITUTE OF METALS, including "*The Journal of the Institute of Metals*," "*Metallurgical Abstracts*," and "*Metallurgical Reviews*," have removed to 17 Belgrave Square, London, S.W.1 (telephone BELgravia 3291). The Advertisement Department and the Joint Library and Information Department remain unchanged at 4 Grosvenor Gardens, London, S.W.1 (telephone SLOane 0061).

The INSTITUTION OF METALLURGISTS have removed from 28 Victoria Street, London, S.W.1, and are now at 4 Grosvenor Gardens, London, S.W.1 (telephone: SLOane 8231) in the premises formerly occupied by the Institute of Metals.

Camp Bird Industries have taken over the whole equity and assets of Hanworth Engineering (Aircraft) Ltd., of Hanworth, Surrey. The Company is to be renamed COLD FORGING LIMITED.

The new Secretary responsible for the periodical "*Metalen*" is J. A. Jochems, Rotterdamse weg 139, Delft, Netherlands.

The METALLURGICAL EQUIPMENT EXPORT COMPANY LTD. and INDIAN STEELWORKS CONSTRUCTION COMPANY LTD. have removed to Abford House, 15 Wilton Road, London, S.W.1 (telephone: TATe Gallery 8191).

Industrial Publications

Illustrated brochure on the activities of the Incandescent Group—The Incandescent Heat Co., Ltd.

Leaflet on specifications for grinding wheels—Norton Grinding Wheel Co., Ltd.

Technical leaflet on wire belt slings—The British Wedge Wire Co., Ltd.

Leaflet on granular compositions for repairing furnace linings—General Refractories Ltd.

Illustrated brochure on heat insulation—Moler Products Ltd.

Technical brochure on lifting and grabbing cranes—Blaw Knox Ltd.

Technical broadsheet on properties of heat-resisting steels for castings—Firth-Vickers Stainless Steels Ltd.

Illustrated brochure on application of photography to industry—Kodak Ltd.

Leaflet on recommendations for cylindrical grinding—Norton Grinding Wheel Co., Ltd.

Technical leaflets on 'Columax' and 'Alcomax SC' permanent magnets—Swift Levick and Sons Ltd.

Technical leaflet on r.f. plastic preheater—Radio Heaters Ltd.

Leaflet on briquetted alloys for enriching scrap—British Electro Metallurgical Company.

Illustrated technical brochure on cutting fluids, oils, and coolants—Fletcher Miller Ltd.

Technical brochures on medium-size high-vacuum melting and pouring induction furnaces and a vacuum furnace of ½-lb capacity—Edwards High Vacuum Ltd.

Illustrated brochure on economics of advanced soaking-pit practice as applied to surface one-way fired soaking pits—Stein and Atkinson Ltd.

CORRIGENDA

In the paper by G. Bullock on "Thermal Changes in Steels as shown by Resistivity" (*J. Iron Steel Inst.*, 1956, vol. 183, August, pp. 362–367), the blocks and captions for Figs. 3 and 4 were confused with those for Figs. 5 and 6, respectively. Thus the diagram on p. 364 is Fig. 5, that on p. 365 Fig. 6, and those at the top of p. 366 Figs. 3 and 4.

In the paper by E. W. Voice and R. Wild on "A Laboratory Study of the Sintering Process" (*J. Iron Steel Inst.*, 1956, vol. 183, August, pp. 404–410), the following corrections should be made. On p. 408, right-hand column, "27–55,000 ft^3" and "75,000 ft^3" instead of "ft^3/min". On p. 409, both references to Fig. 4 should be to Fig. 5.

DIARY

2nd–10th Oct.—NATIONAL INDUSTRIAL FUEL EFFICIENCY SERVICE and COMBUSTION ENGINEERING ASSOCIATION—Fuel Efficiency Exhibition—Olympia, London.

3rd Oct.–5th Dec.—INSTITUTE OF WELDING—Course of Lectures on "*Detail Design of Welded Structural Steelwork*"—Junior Institution of Engineers, Rochester Row, London, S.W.1.

4th Oct.—LEEDS METALLURGICAL SOCIETY—"*Testing*," by A. Lenton—Large Chemistry Lecture Theatre, The University, Leeds, 7.15 P.M.

4th–5th Oct.—IRON AND STEEL INSTITUTE, Engineers Group—Meeting at Port Talbot, South Wales.

6th–12th Oct.—AMERICAN SOCIETY FOR METALS—38th National Metals Congress and Exposition, Cleveland, Ohio.

7th–10th Oct.—ASSOCIAZIONE ITALIANA DI METALLURGIA—National Convention—Palazzo del Consiglio Nazionale delle Ricerche, Rome.

11th Oct.—LIVERPOOL METALLURGICAL SOCIETY—Presidential Address, by W. Rose, J.P.—Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7 P.M.

12th Oct.—IRON AND STEEL INSTITUTE and BRITISH IRON AND STEEL RESEARCH ASSOCIATION—Corrosion Meeting—4 Grosvenor Gardens, London, S.W.1, 10 A.M.

12th Oct.—NEWPORT METALLURGICAL SOCIETY—Annual Dinner, Newport, Mon., 7 P.M.

13th Oct.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Presidential Address, by R. Walker—Central Library, Swansea, 6.30 P.M.

15th–28th Oct.—ECONOMIC COMMISSION FOR LATIN AMERICA, UNITED NATIONS—Latin American Meeting of Experts on the Steelmaking and Transforming Industries—São Paulo, Brazil.

19th Oct.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Symposium on "*The Application of Low-alloy Steels for Welded Pressure Vessels*"—39 Elmbank Crescent, Glasgow, C.2, 10 A.M.

22nd–27th Oct.—SOCIÉTÉ FRANÇAISE DE METALLURGIE—Autumn Meeting, Paris.

23rd–24th Oct.—GESELLSCHAFT DEUTSCHER HÜTTENLEUTE—Second Congress—Leipzig.

24th Oct.—LIVERPOOL METALLURGICAL SOCIETY—Visit to Meccano Ltd., Binns Road, Liverpool 13.

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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MINERAL RESOURCES

Chromite Production at Pium-i (Brazil). E. Frias Rocha. (*Rev. Quim. Industr.*, 1954, **23**, Dec., 14–18). [In Portuguese]. The chrome ore deposits (up to 45% Cr_2O_3) are in the Serra do Andaime (Andaime Mountains). An account is given of the transportation costs to the industrial centres (300 miles to Belo Horizonte). The geology of the main regions which have been explored and exploited is given.—R. S.

Monazite Deposits in the Rio Grande do Norte State (Brazil). (*Rev. Quim. Industr.*, 1955, **24**, Jan., 11). [In Portuguese]. The Brazilian National Department for Mineral Production has just revealed the existence of one of the most important monazite deposits in Brazil at Floriania in the region of Seridó in the State of Rio Grande do Norte. These deposits are associated with zirconium. No further details are given.

ORES—MINING AND TREATMENT

Underground Mining in the Frodingham Ironstone. A. Jones. (*Bull. Inst. Min. Met.*, 1956, **65**, April, 253–272; June, 422–430). An account of the geology of the deposit and methods of working employed.

The Mining and Dressing of Low-Grade Ores in Europe. (*Organisation for European Economic Co-operation*, T.A.R. 127 (54) 1, June, 1955, 1–319). The object of the mission was to examine the facilities available for research and the practical results achieved in the mining of low grade ore in Great Britain, Sweden, Germany, Italy and France. Only in Germany were manufacturing plants examined. Problems associated with the improved exploitation of low-grade ores are considered and recent interesting developments in research and practice are reported. Details of plants and laboratories are given in a series of appendices.—B. G. B.

Sintering Iron Ore. Process Control at Appleby-Frodingham Steelworks. R. A. Kipling and N. D. Macdonald. (*Process Control*, 1955, **2**, Jan., 9–14). The control system for the Appleby-Frodingham sinter plant is described. This falls under three main headings, namely, the control of supply, mixture, and the sintering process. All equipment except the sintering machines and the surge bin feeder tables are started up in a predetermined sequence. The feeder tables are fed from an M.K. set, enabling the feed rates to be varied whilst keeping the constituents at a constant ratio; the coke table is energised separately. The supply of water is adjusted from the control room. Combustion rate, air supply, strand speed and fuel are controllable, and an overall coordinating control is exercised from the control room. Possibilities of further development in the direction of fully-automatic control are discussed.—L. D. H.

The Reproducibility of Test Results in an Experimental Sinter Box. C. Lang and J. M. Ridgion. (*J. Iron Steel Inst.*, 1956, **183**, 172–177). [This issue].

New Sintering Plant in Operation at Steel Company of Canada. J. S. McMahan. (*Blast Furn. Steel Plant*, 1955, **43**, Dec., 1369–1376, 1385–1386). A detailed description of this new sinter plant manufactured by Lurgi is given. The plant is of the Dwight Lloyd type and has one strand with a design capacity of 1700 tons/day. The stand is 98 ft. long × 6 ft. 6 in. and has 16 windboxes. A grease seal is employed. The fan is powered by a 1750-h.p. motor and is designed to operate at 39·4 in. suction and 302° F. Cooling of the sinter takes place on an inclined cooling conveyor.—B. G. B.

Operating Experience at the Kamysh-Burunsk Sinter Plant. D. I. Vasil'ev and V. A. Arbuzov. (*Stal'*, 1955, (4), 302–305). [In Russian]. Recent operating experience at a sinter plant dealing with an ore containing up to 96–97% of 0–8 mm fines and 23–24% moisture. The charge normally contains 25–28% return fines, which are added hot, and result in the charge temperature rising to 45–50° C and moisture falling to 13–14%. The fuel is coke fines with 13–15% ash and 16–17% moisture. Through various improvements the fuel consumption fell from 167 kg per ton sinter in 1952 to 157 in 1953, the corresponding figures for electrical energy being 24·2 and 21·6 kWh. Further improvements to be undertaken are listed.—S. K.

FUEL—PREPARATION, PROPERTIES, AND USES

High Temperature Reactions for Coal Minerals During Combustion. G. Whittingham. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1954, **18**, Dec., 581–590). Information on the chemical reactions of coal minerals under combustion conditions is reviewed under the headings sulphides, carbonates, chlorides and silicates. (40 references.)—D. L. C. P.

Combustion Efficiency, Flue Gas Analysers, and Atmospheric Pollution. J. C. Farquhar. (*Fuel Econ. Rev.*, 1956 **34**, 73–78). This article deals with the combustion processes in furnaces from the standpoint of the provision and proper utilization of combustion air. The adequacy of the total air

supply can best be determined by a continuous oxygen analyser, but warning of incomplete utilization of the air must be given by a smoke or combustibles indicator. The effects of air supply and combustion conditions on atmospheric pollution and combustion efficiency are briefly discussed.—D. L. C. P.

The Significance of Reactions of Low Activation Energies to the Mechanism of Combustion. F. J. Weinberg. (*Proc. Roy. Soc.*, **A,** 1955, **230,** June 21, 321–342). Considerations of activation energy suggest that combustion mechanisms may be simply regarded in terms of single rate-controlling chain-branching and -breaking steps; these may be derived from measurable flame properties. Flame propagation, burning velocities, etc. are discussed.—K. E. J.

The Radiation from Turbulent Jet Diffusion Flames of Liquid Fuel/Coke Ovens Gas Mixtures. (*J. Inst. Fuel*, 1956, **29,** Jan.). The articles deal with Performance Trials Nos. III, IV and V of the Flame Radiation Research Joint Committee, carried out on the pilot scale furnace at Ijmuiden.

1. **Purpose of the Trials and Practical Implications of the Results.** The International Flame Research Committee. (23–26). Tests were carried out with mixtures of liquid and gaseous fuels, to determine the effect of their proportions on radiation from the flames. It was found that the replacement of 20% of the gas with liquid fuel gives an increase in emissivity of 30% compared with that of a 100% liquid fuel flame which is 4 times that of a coke-oven gas flame in the early part of the flame. On the other hand 30% of creosote-pitch or 20% of oil can be replaced by coke oven gas without appreciable loss of emissivity compared with the 100% liquid fuel flame.

2. **Methods of Increasing the Emissivity of Coke-oven-gas Flames without Addition of Liquid Fuels.** M. W. Thring (27–30). After considering published work, it is concluded that promising methods of increasing emissivity of coke-oven-gas flames are (1) pure preheat of the gas, (2) preliminary partial combustion of the gas.

3. **Conduct of the Trials and their Results.** M. Rivière. (31–44). The experimental conditions are indicated. Variables were fuel quantity; combustion air quantity; jet momentum quantity; fuel quality. The results show the influence of each of the variables on the flame radiation and the temperature of the walls, as well as the interaction between the variables.—D. L. C. P.

Generating Power in Steelworks: The 120,000 kW Power Station at the Herserange Steel Works. A. Evain. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, S7, 1–4). An outline is given of the development of power generation in the Briey Basin of Lorrain from small individual works generators to two large centralized power stations. The latter provide the most efficient method of utilizing surplus blast-furnace gas available in the district.—E. C.

A New Gas Engine at Cockerill. A. Vandeghen. (*Rev. Tech. Luxembourg.*, 1955, **47,** Apr.–June, 115–116). A short description of new engines using a mixture of blast-furnace gas and oil, at the Société Cockerill for driving blast-furnace blowers is given.—B. G. B.

The Gas Turbine Division of Dudelange (ARBED). M. Steffes and P. Mosel. (*Rev. Tech. Luxembourg.*, 1955, **47,** Apr.–June, 75–81). A description is given of a 7-stage gas turbine designed to use blast-furnace gas or fuel oil and to operate up to 600° C and 2·8 kgms/cm². The turbine is used for electric generation and has been very satisfactory in operation.—B. G. B.

Coal and the Future. W. I. Jones. (*Swansea Met. Soc. Advance copies*, 1954, Dec. 4, 1–15). The production and utilisation of coal and other fuels in U.K. are briefly discussed; present conditions and knowledge are presented and possible trends in fuels and chemicals over the next 50 years are considered.—D. L. C. P.

Fuel Statistics. K. R. Lenel. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1955, **19,** Jan., 1–8). References are given to world-wide statistics on (*a*) fuel reserves, (*b*) rank or type of solid fuel reserves, (*c*) analyses of solid fuels, (*d*) production and consumption; also to informed comment on these figures. Brief notes about the information are given. (46 references).—D. L. C. P.

The Theoretical Bases of Heat Recuperation. A. Schack. (*Chaleur et Ind.*, 1956, **37,** Jan., 11–15). The theory is given and discussed, and the economics of recuperation are briefly indicated.—T. E. D.

The Problem of Dust in the Construction of Recuperators. G. Wellensiek. (*Chaleur et Ind.*, 1956, **37,** Jan., 21–24). In connection with this problem the principles of a slagging gas producer with an agitated slag bath as reaction medium, a radiation recuperator and a convection recuperator are briefly described.—T. E. D.

Problems Facing the By-Product Coking Industry. A. K. Shelkov. (*Stal'*, 1955, (8), 675–678). [In Russian]. A broad survey is given of recent developments in the coking industry of the U.S.S.R., with special reference to the requirements of iron and steel production. Problems confronting the industry are discussed.—S. K.

Coke-Ovens of the Iron-Smelting Industry in the Lorraine Valley. J. de Miscault. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 18, 1–5). A brief survey is made of the historical development and present day technical and economic problems of the production of metallurgical coke in Lorraine.—E. C.

The Sidelor-Micheville Coke Oven Plant at Villerupt. M. Cornuat. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 13, 1–8). Details, data, and material balances are given for several months of normal operation of this plant which comprises two batteries of Becker "Disticoke" type and a standard coal preparation plant.—E. C.

A Description of the Coke Plant Equipment at Neuves-Maisons, for Handling Different Coal Mixtures. First Operating Results. L. Odile. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 14, 1–6). A brief account is given of the features of a new coke oven plant designed to work with a large variety of mixtures of coals including high proportions of low-coking types.—E. C.

Consett No. 2 Coke-Oven Battery. (*Coke Gas*, 1956, **18,** Feb., 73–74). Demolition and construction problems encountered when old ovens were replaced by 20 new Wilputte ovens are briefly described. The job was carried out without shutting down the part of the battery not being replaced.

The New "Emma" Coking Plant of the Netherlands State Mines. J. P. M. van Waes and H. E. Quanjel. (*Coke Gas*, 1956, **18,** Mar., 83–87; Apr., 117–122). A number of unusual features, such as the use of oxygen for the manufacture of fuel gas for heating the ovens, are employed in the plant, which is here described. Notes are given concerning the gas cooling and ancillary plant, ammonia recovery, benzole extraction and refining, and the slagging generators using oxygen and steam for the manufacture of oven heating gas.

Proceedings of the Conference on the Construction of Large-Capacity Coke Ovens. R. Z. Lerner. (*Stal'*, 1955, (5), 396–397). [In Russian]. At a conference organized by the Ministry of Ferrous Metallurgy, the building in the U.S.S.R. of two experimental coke ovens was recommended, the proposed chamber widths, lengths and heights being 450, 15,000 and 5000 mm, respectively.—S. K.

The Contribution of the Saar Mines in the Use of Low Grade Coking Coals for the Production of Metallurgical Coke. J. Bamal. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 11, 1–9). Brief accounts are given of various successful trials in producing good metallurgical cokes from complex blends using low-grade coking coals from Saar mines. The replacement of binders by a ramming treatment was also investigated with promising results.—E. C.

The Production of Coke and Gas in the Bassin du Nord and Pas-de-Calais Areas. M. Malherbe. (*Centenary Congress of the Société l'Industrie Minérale*, June, 1955, Sa. 22, 1–7). A survey is made of technical and economic problems created by the necessity for balancing and co-ordinating the requirements of coke and gas consumers in these districts. An outline is given of planned reconstruction and modernization of equipment.—E. C.

The Development of Carbonisation in France and Technical Aspects of its Economics. J. Sabatier and J. Moussu. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 20, 1–5).

Carbonization of Lorraine Coals at Thionville. C. Mehl. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 12, 1–8). Results are surveyed of full-scale tests in the production of metallurgical coke from coal mixtures with high V.C.M. content (31·5% average), using the "Sovaco" process.—E. C.

The Incorporation of Fuel Oil in a Metallurgical Coke Blend Containing 60 per cent of High-volatile Coal. H. Decalf. (*Centenary Congress of the Société de l'Industrie Minérale*, June,

1955, Sa. 10, 1–8). A brief account is given of experiments with the addition of fuel oil to coke mixtures containing high proportions of high-volatile coal. Data are given from the resulting satisfactory industrial production of blast furnace coke, using 0·4% of fuel oil and 60% of high-volatile coke in the feed.—E. C.

The Development of the Carling Process for the Production of Coke from Lorraine Coals. J. Deruelle. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 9, 1–7). A brief account is given of the principle and development of the Carling process of producing coke from prepared mixtures of coals with the addition of coke dust and the use of ramming to produce high density charges. The associated by-products industry is outlined.—E. C.

New Processes for Improving Coke. A. Jenkner. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 6, 1–21). Details are given of investigations concerning the production of good metallurgical coke from Ruhr coking coals with additions of high and low volatile coals. The French "Sovaco" process of selective blending and crushing was adopted, producing coke of great uniformity and excellent physical properties. Improved coke-oven performance resulting from the uniform feed is expected to offset higher plant costs.—E. C.

Dry Cake Coking. R. Loison. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 5, 1–7). By using a dry cake mix the production capacity of a coke oven may be increased by up to 24%. Details are given of results found in practice and the economic aspects of this method of producing coke.—E. C.

Low-Temperature Carbonization of Lignite and Non-Coking Coals in the Entrained State. V. F. Parry, W. S. Landers, and E. O. Wagner. (*Min. Eng.*, 1956, **8**, Jan., 54–64). Pilot-plant work, with fluidized drying and carbonization techniques, shows that lignite can be upgraded for use in power plants. The fuel cost is offset by tar yields of 10–45 gal/ton.—K. E. J.

The Use of Metallurgical Coke in Lorraine. V. Remond and J. Cyther. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 17, 1–8). Conditions of blast furnace operation peculiar to Lorraine are outlined and effects of coke properties on furnace performance are considered.—E. C.

Results of Using Carling Coke in the Blast Furnace. M. Legendre, P. Michaux, and P. Thierry. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 16, 1–8). Results are reported of full-scale tests at three Lorraine blast-furnace plants with the substitution of Carling coke for high-grade Ruhr coke. Carling coke is a Lorraine-made product based on a mixture with high proportions of non-coking coals. Within the limitations of assessment accuracy Carling coke was found fully equivalent to the Ruhr product.—E. C.

A Study of the Properties of Six Cokes. Ch. G. Thibaut, P. Vigneron, and B. Menuet-Guilbaud. (*Centenary of the Société de l'Industrie Minérale*, June, 1955, Sa. 15, 1–11). A preliminary report is made on results obtained to date in a comprehensive programme of investigation instigated by IRSID. Six French cokes are being studied in all conceivable respects and data from 12 laboratories are being compared.

New Methods for Assessment of the Quality of Metallurgical Coke. M. Th. Mackowsky. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 7, 1–12; *Glückauf*, 1955, **91**, Aug., 221–230). An attempt is made to relate coke quality to porosity, and factors influencing porosity are investigated. A new method of determining coke reactivity (as compared with CO) is described, and relationships are traced between reactivity, mechanical strength and quality of metallurgical cokes.—E. C.

Natural Gas Burners for Industrial Furnaces. M. Tesio. (*Calore*, 1955, **26**, Mar., 123–135). [In Italian]. This paper gives a detailed description of seven different types of gas burners and discusses their applications to different types of industrial furnaces including open hearth furnaces. (27 references).—M. D. J. B.

Total Gasification of Coal in Great Britain. A. R. Myhill. (*Gas Times*, 1956, **86**, Feb. 3, 71–74). The question of whether gas manufacture should continue with co-production of a solid-fuel residue, or whether complete gasification should be adopted, is examined. The theory and practice of total gasification are discussed, and the Lurgi process is described.

Developments in Gas-Producer Practice. G. W. C. Allan. (*J. Inst. Fuel*, 1955, **28**, Sept., 458–462). Developments in producer design and practice over the last 5 years are reviewed. Particular activity is noted in the following fields: 2-stage machines; automatic control; clean gas.—D. L. C. P.

The Removal of Hydrogen Sulphide from Coke Oven Gas Using Closed Circuit Pressure Washing. W. Klempt and G. Huck. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 21, 1–9; *Glückauf*, 1955, **91**, Aug., 215–220). The principle and process are described of a method of desulphurizing coke oven gas under pressure with ammonia solutions of low concentration. 95 to 100% removal of H_2S is claimed.—E. C.

Recent Developments in the Measurement of Dust Content in Industrial Gases. K. Guthmann. (*Stahl u. Eisen*, 1955, **75**, Nov. 17, 1571–1582). Quantitative measurement of dust content is discussed, followed by a review of suitable filter materials. Apparatus for the measurement of large and small dust particles is described, and the method of calculation of dust content indicated. Sources of error are referred to.—A. C.

The Performance of a Wellman-Galusha Producer Installation with a Whessoe Gas-cleaning Plant. J. A. Grainger. (*J. Inst. Fuel*, 1955, **28**, Dec., 594–600). The problems encountered in ensuring a reliable supply of gas at a competitive price from a coke producer-gas installation supplying a large steelworks are described. Performance data are given. At high load factors the plant is capable of producing and distributing gas at a competitive price.—D. L. C. P.

Reactions of Carbon with Carbon Dioxide and with Steam C. G. von Fredersdorff. (*Gas Times*, 1956, **86**, Feb. 3, 68–70). Carbon–carbon dioxide reactions at atmospheric pressure, and carbon–steam reactions at atmospheric and super-atmospheric pressures were studied in fixed beds under steady state conditions. Apparatus is described and results are given.—T. E. D.

TEMPERATURE MEASUREMENT AND CONTROL

Calibration of Temperature Measuring Instruments. (*National Physical Laboratory, Notes on Applied Science*, No. 12, 1955). Details of standard test procedures for mercury thermometers, thermocouples, resistance thermometers, disappearing filament pyrometers, and tungsten strip lamps are given.—B. G. B.

Influence of Humidity on Measurements with Radiation Pyrometers. R. Smit. (*Appl. Sci. Res.*, 1956, **B5**, No. 6, 428–436). Calculations are given for determining errors caused by absorption by water vapour, and experimental checks are included.

REFRACTORY MATERIALS

Production of Forsterite Refractories: Composition, Characteristics and Utilisation of Magnesite-talc Schist. S. Sen and R. Singh. (*J. Sci. Indust. Res.*, 1955, **14B**, Dec., 656–665). Addition of 25% excess of magnesite on the weight of magnesite-talc and a firing temperature of 1500° C are the optimum conditions necessary for the production of high temperature refractories with a Pyrometric Cone Equivalent of 38.—E. E. W.

Model Tests in the Brick Industry. J. Voskuil. (*Chem. Week.*, 1955, **51**, Nov. 19, 835–844). [In Dutch]. The author examines, with the help of several examples, the aerodynamic phenomena occurring in drying ovens as used in the ceramic industry and calls attention to the difficulties connected therewith which seem hitherto not to have been particularly well understood. Numerous illustrations of draught systems in furnaces appear and the paper concludes with a bibliography of 28 references on the subject.—F. R. H.

Studies on the Corrosion of Pouring-Pit Refractories by the Molten Steels and Slags. I. S. Maekawa and Y. Nakagawa. (*Tetsu to Hagane*, 1955, **41**, Dec., 1237–1243). [In Japanese]. Studies were made with chamotte bricks, containing SiO_2 63, Al_2O_3 34·5, Fe_2O_3 2·5 and CaO 0·11%, approx. Corrosion was influenced mainly by the Mn and FeO contents of molten steel, Si reducing it. The reactions for corrosion by Fe, Mn and FeO are discussed quantitatively. (12 references).

The Behaviour of Refractory Materials to Thermal Stresses. L. Massimilla and S. Bracale. (*Met. Ital.*, 1955, **47**, Nov., 511–518). [In Italian]. An attempt is made to interpret the results of tests carried out on refractory materials subjected to different thermal cycles. The effects of modulus of elasticity, thermal diffusivity, thermal expansion, and mechanical strength are examined in detail. The authors stress

the importance of the structure of the material and suggest a 'homogeneity factor' to be added to the test of factors which help to define quality in refractories.—M. D. J. B.

Testing the Strength of Refractories by Sudden Thermal Changes. A. Giannone and L. Massimilla. (*Met. Ital.*, 1955, **47**, Oct., 461–464). [In Italian]. After giving a brief review of refractory tests specified in different countries, the authors put forward a method similar to the American panel tests but suitably modified to reproduce as far as possible the actual working conditions which refractories have to stand up to. The method is based on theoretical studies indicating temperature and stress distributions. Tests carried out on silica, magnesia, and silico-alumina bricks are described.—M. D. J. B.

Recent Research on the Chemistry of Open-Hearth Roof Refractories and its Bearing on Durability. J. White. (*West Scotland Iron Steel Inst.*, Paper No. 488, Mar. 16, 1956). The author examines recent work on this subject and considers the factors determining the resistance of silica bricks to fluxes, the action of iron oxides and flux penetration. Attention is then directed to the basic roof and the general properties of chrome magnesite refractories are reviewed, including the phase relationships. The author concludes with a consideration of the equilibrium relationships of the iron oxides in chrome refractories. (41 references).—L. E. W.

Casting Pit Refractories. (*Ceramics*, 1955, **7**, March, 12–18). Casting operations are described, and refractories suitable for the various conditions are considered.—D. L. C. P.

Zircon as a Refractory Material. B. L. Majumder. (*Ceramics*, 1956, **7**, Jan., 465–468; Feb., 497–499). The nature, availability, and refractory properties of zircon are considered in Part 1, and the uses of the refractory in Part 2. Resistance to coal-ash slags is good but there is some reaction with basic iron slags.—D. L. C. P.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Progress of the Pig Iron Making Process in Japan. K. Wada. (*Tetsu to Hagane*, 1955, **41**, July, 714–722). [In Japanese]. Developments since the end of the war, when production was hampered by the poor quality of raw materials, include 1200 tons per day production on one furnace, and a national average coke rate of < 700 kg per ton of Fe (one furnace operates at 680 kg); they are attributed to new plant, quality control of coke, and high-sinter burdens.—K. E. J.

The Russian Iron and Steel Industry. (*Iron and Steel Institute, Special Rept. No.* 57. 35 pp.). This is the report of a British Steel Mission on a visit to the U.S.S.R. It covers organization, raw materials and transport, plant and operations, research and development, personnel, and education and training. There are 5 illustrations and a map.

The Russian Iron and Steel Industry. W. F. Cartwright. (*Engineering*, 1955, **180**, Dec. 2, 755–756). See previous abstract.

International Collaboration in Iron and Steel Research. P. Coheur. (*Rev. Soc. Roy. Belge Ing. Indust.*, 1955, Dec., 494–509). The development of the low shaft furnace project at Liège is described as a particular case of international research. A number of other international research projects is mentioned.—B. G. B.

Performance Criteria for Hot-Blast Stoves. S. Szczeniowski. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sf 4, 1–10). Methods and criteria are discussed for assessing the performance of Cowper stoves in respect of gas consumption, rate of heat exchange, and heat storage capacity.—E. C.

Various Types of Cowper Stoves Used as Heat Accumulators. D. Sanna and M. Pasquet. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sf3, 1–51). A detailed account is given of a series of investigations and full-scale trials carried out by I.R.S.I.D. from 1950 to 1953. The principle and problems of heat storage are explained and results of the tests are discussed. The trials were carried out at various plants in Lorraine and full data are given in each case. The balance of benefits of heat storage against gas losses and refractory consumption is considered.—E. C.

On Improvements of the Blast Furnace Practice. C. Sakai. (*Tetsu to Hagane*, 1955, **41**, Dec., 1228–1232). [In Japanese]. An account is given of improvements to practice at No. 2 furnace of Kokura Steel Works, producing low-copper, low-sulphur iron. These concerned raw materials preparation, increased quality and production of sinter, slack wind blowing, and the use of elliptical tuyeres. The output has exceeded 400 tons per day and the coke rate is below 14 cwt. per ton.—K. E. J.

Desulphurization of Pig Iron with Calcium Carbide. S. Kawabata and M. Okami. (*Tetsu to Hagane*, 1955, **41**, Dec., 1244–1246). [In Japanese]. Desulphurization trials were made with CaC_2 and CaO powders injected in streams of nitrogen and air. The best results were obtained with 1% of CaC_2 in nitrogen; at temp. above 1350° C, the sulphur content was reduced to 20% of its original value or less. Full-scale applications of the process are described.—K. E. J.

Fundamental Research on Cinders as Pig Making Material. II. T. Akimoto and S. Onishi. (*Tetsu to Hagane*, 1955, **41**, Dec., 1223–1228). [In Japanese]. Investigations were made of pyrite and pyrrhotite residues from sulphuric acid manufacture. The former was reduced more easily by CO and solid carbon, and had a higher permeability at high temp. (12 references).—K. E. J.

The Influence of Coke Circulation on the Combustion Process in Blast Furnaces. I. P. Bardin, M. Ya. Ostroukhov, L. Z. Khodak and L. M. Tsylev. (*Izvest. Akad. Nauk, SSSR, Otdelenie Tekn. Nauk*, 1955, (1), 80–95). [In Russian]. The combustion zone in front of tuyeres was investigated in four blast furnaces. The distributions of oxygen, carbon dioxide, carbon monoxide, temperatures, and static pressures along the radius in front of the tuyere nozzle were measured and samples of slag and metal were collected. On the basis of results obtained it is concluded that the combustion in a blast furnace takes place not in a layer of coke but in a stream of blast in which pieces of coke are suspended. Only the last stage of combustion, the reduction of carbon dioxide to carbon monoxide, takes place in the boundary layer of coke surrounding race ways.—V. G.

On the Behaviour of Zinc in Blast Furnaces. A. L. Zagyanskii. (*Ivest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955 (1), 96–108). [In Russian]. The difficulties in furnace operation which may be caused by zinc are outlined. General characteristics of zinc minerals present in ores and sinters is given and the behaviour of zinc at various furnace levels is discussed.—V. G.

No. 4 Blast Furnace at Margam. (*Engineering*, 1956, **181**, Jan. 20, 68). A brief description is given of the new 29 ft. 9 in. blast furnace at the Margam Works of the Steel Company of Wales. The blast furnace, the largest in Europe, will make upwards of 10,000 tons of iron a week. Air for the furnace is provided by a 125,000 cu. ft./min. steam-driven axial-flow turbo-blower supplied by The Oerlikon Engineering Co. of Zurich. The furnace is equipped with 4 gas-cleaning units. Slag from the furnace is run into pits from which it will be loaded by diggers into road vehicles and conveyed to tips.—M. D. J. B.

Iron and Steel. W. F. Cartwright. (*Engineer*—Centenary Number 1955, 174–177). Brief details are given of the notable engineering developments which have taken place in the iron and steel industry. Special reference is made to hydraulic engineering, to the cleaning of blast furnace gas and to speed control equipment of cold rolling mills.

Progress in the Fuel Efficiency of the Blast Furnace. A. H. Leckie. (*J. Inst. Fuel*, 1955, **28**, Dec., 618–624). The influence of the following factors on the coke consumption of blast furnaces since 1920 is considered:—1. Richness of ores, 2. Type of iron made, 3. Quality of burden, 4. Quality of coke, 5. Size of furnace. The trend of decreasing coke consumption is mainly due to burden preparations and increase in the size of furnaces. Efficiency in the use of blast furnace gas is also considered. (40 references).

Horizontal Distribution of Materials in the Throat. V. K. Gruzinov. (*Stal'*, 1955, (4), 305–311). [In Russian]. The various types of uneven distribution of materials in the blast-furnace throat are discussed and related to charging method and especially to distribution on the small bell. The significance of curves of carbon dioxide contents along various radii and at different distances from the wall is considered. The theory of horizontal distribution, which is considered of greater significance than vertical, is discussed in detail. Ore and coke layers are sketched out for different charging cycles, and the practice recently reported from the Park Gate works is reviewed.—S. K.

Electric Smelting of Titaniferous Ironsands at Onekaka. T. Marshall and D. S. Nicholson. (*New Zealand J. Sci. Tech.*, 1955, **37**, Sept., 201–220). The ironsands contain over 50% iron after concentration but owing to the high titania content (7%) cannot be smelted in a conventional blast furnace. Tests using electric smelting techniques are described and show that the ironsands could be smelted in a continuously-operated electric furnace.—B. G. B.

Electric Smelting of Ilmenite Concentrates from Valley County, Idaho. L. H. Banning, W. F. Hergert and D. E. Halter. (*U.S. Bur. Mines Rep. Invest.* 5170, 1955, Nov.). Electric smelting of alluvial ilmenite from Idaho containing 34–35% Fe and 39–45% TiO_2 is described. The results obtained are satisfactory and indicate it is possible to produce a slag containing over 80% TiO_2 and a marketable pig iron. It is considered that further tests should be carried out.

Desulphurization of Iron in the Electric Smelting Furnace. B. Marinček. (*Stahl u. Eisen*, 1955, **75**, Aug. 11, 1024–1026). Operational results on an 8000 kW electric low shaft furnace show that of the sulphur introduced with the burden some 8% enters the metal, 67% is absorbed by the slag and 25% is carried away with the waste gases. It is shown that silicon and carbon in the metal make desulphurization more effective by reducing the oxygen potential of the metal and so facilitating pick-up of sulphur by the slag. The desulphurization results are shown graphically and it is suggested that they could be employed in other types of blast furnace.

Pastes for Söderberg Arc-Furnace Electrodes. K. N. Cederquist. (*Jernkontorets Ann.*, 1955, **139**, (11), 893–922). [In Swedish]. Various explosions caused by unsatisfactory composition of electrode pastes were investigated and were ascribed to undesirable swelling properties as a result of wood tar content. Details are given of an investigation of the faulty pastes and of some 20 other grades. Attempts to find a simple acceptance test for pastes are described, and it is concluded that the general character of the paste can best be studied by testing the softness of samples at various temperatures. Tests showed that electrode strength is not improved by adding surface-active agents.—G. G. K.

TREATMENT AND USE OF SLAGS

Surface Structure of Nonoxidising Slags Containing Sulphur. R. E. Boni and G. Derge. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Jan., Section 1, 59–64). The authors have studied the effect of sulphur on the surface tensions of synthetic blast-furnace slags. Low surface tension is found to be associated with high basicity; sulphur lowers the surface tension of basic BaO, basic CaO, acid BaO, acid CaO, and acid MgO slags in amounts increasing in that order, and the concentration of excess sulphur at the slag surface increases in the same order. Desulphurization is favoured by a low excess surface sulphur in the slag.—G. F.

Spectographic Solution Methods for Slag Analysis. S. Bergenfelt. (*Jernkontorets Ann.*, 1956, **140**, 1, 75–80). [In Swedish]. Details are given of two methods. In the first the powdered sample and cupric oxide are dissolved in hydrochloric acid, the solution being filtered to remove the silica. Part of the solution is transferred to a small glass cup and carried to an a.c. spark by a rotating graphite disc which dips into the solution. The cupric oxide serves as an internal standard. In method 2 the sample is fused with borax, dissolved in a solution containing citric acid and cobalt nitrate as the internal standard, and spark excited as above.—G. G. K.

On Transfer Numbers of Calcium Ions in the Simplest Molten Slags. O. A. Esin and A. K. Kir'yanov. (*Izvest. Akad. Nauk SSSR., O.T.N.*, 1955, **12**, 28–34). [In Russian]. Ionic nature of the conductivity of slags in the $CaO–SiO_2$ and $CaO–Al_2O_3$ systems was confirmed by measurements of transfer numbers of calcium ions at temperatures 1450–1460°C using radioactive calcium.—V. G.

DIRECT PROCESSES

A Little-Studied Aspect of the Spanish Metallurgical Problems. G. Arregui Echeverria. (*Met. Elect.*, 1955, **19**, Oct., 49–52; Nov., 53–56). [In Spanish]. It is pointed out that the large scale iron and steel making plants are handicapped by a lack of flexibility which is required if low grade natural resources are to be handled. The small local plants can adapt more easily and could deal with low grade ores by modern direct reduction processes. The fundamental physico-chemical reactions of these processes are closely paralleled in the blast furnace, and these are described in illustration.—P. S.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Dusseldorf:

The Krupp-Renn Process. D. Fastje (19–24). The author recapitulates the more important features of the Krupp-Renn revolving-kiln process and describes some recent developments. The economics of the process are assessed.—G. F.

The Simultaneous Production of Cast Iron and Cement in a Rotating Furnace. (Basset Process). (*Usine Nouvelle*, 1955, Oct., 13–17). Iron ore (5 to 10 mm), coal or coke fines, and pure limestone, in accurately calculated quantities, are heated together in a rotating furnace of the type used in the cement industry. Reduction is complete at 1100° C. At this temperature the slag is not molten but in an agglomerated state. Slag composition is approximately that of artificial Portland cement. Details are given of the method and raw materials, quality of the products, and actual and possible industrial applications.—T. E. D.

PRODUCTION OF STEEL

Proceedings of the All-Union Steel-Making Conference. D. A. Smolyarenko. (*Stal'*, 1955, (7), 652–653). [In Russian]. An account is given of a conference held at Zaporozh'e in March-April, 1955, at which modern steel-making practice in the U.S.S.R. was discussed and recommendations for future work made.—S. K.

Steelmaking Since Bessemer. Sir Charles Goodeve. (*J. Iron Steel Inst.*, 1956, **183**, 113–118). [This issue].

Quality of Metallurgical Production in Southern Works. A. M. Robustov and G. A. Olesin. (*Stal'*, 1955, (7), 656–658). [In Russian]. After a general comparison of the quality of iron and steel production in works in the Ukraine region with that in other localities, blast-furnace, steel-making and rolling-mill practice are considered.—S. K.

The Economics of Four Steelmaking Processes. A. Děkanovsky. (*Hutnické Listy*, 1956, **11**, (2), 65–76). [In Czech]. Costs of steel production in large basic open-hearth furnaces melting low-phosphorus charges by the ore process, large open-hearth furnaces operating the Talbot process, in the converter using the oxygen lance, and by using the acid converter and the basic open-hearth tilting furnace in the duplex process are compared. The converter method, with oxygen lancing, is shown to be cheapest.—P. F.

Progress of Steel Making Process in Japan. S. Hachiya. (*Tetsu to Hagane*, 1955, **41**, July, 723–731). [In Japanese]. The rehabilitation of the Japanese industry since the war, marked by the commencement of importation of ore in 1948, and assistance from the U.S.A., is surveyed. Improvements have been made by using oil firing of open-hearth furnaces, instrumentation, and oxygen steelmaking. Low fuel consumption rates of 7×10^5 kcal. per ton of steel have been achieved. The 1953 ingot production was $7{\cdot}65 \times 10^6$ tons.

A New Process for Melting Metals by Means of Solar Energy. F. Trombe and M. Foex. (*Compt. Rend.*, 1955, **240**, Jan. 10, 196–198). The design of two furnaces using solar energy is briefly described. In an experiment in which more than 80 kg of iron was melted, the ingots produced were homogeneous. The introduction of carbon and the elimination of oxide were possible, in the latter case by the addition of aluminium or a suitably selected flux.—G. E. D.

Monolithic Converter Linings. J. Davies. (*Trans. Amer. Found. Soc.*, 1955, **63**, 71–75). The practices used for grading, ramming, drying, and patching a monolithic lining of bentonite and crushed quartz for a small side-blown converter are described. The lining has a considerably greater life than silica brick.—B. C. W.

Continuous Temperature Measurement of the Bath Applied to Conducting the Refining Process in a Bessemer Converter. B. Trentini, P. Leroy, and M. Gombert. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sc. 3, 1–16). Principles and details are reported of the control of the refining process in a Bessemer converter based on the use of a recording optical pyrometer which is focused on the bath through a hole in the converter bottom. Various actual and theoretical temperature curves are discussed in relation to the chemical evolution of the melt and the dephosphorization of the metal.—E. C.

A New Contribution to the Manufacture of Basic Bessemer Steel with a Low Non-Metal Content. P. Leroy, B. Trentini, and E. Devernay. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sc. 2, 1–30). Details and results are given of a comprehensive investigation of the major factors affecting the final composition of extra mild basic Bessemer steel with a low non-metal content. Specific suggestions based on this work include oxygen enrichment in two stages, chart-controlled blowing, oxidizing additives, accurate control of final temperatures, and double desulphurization in the ladle.—E. C.

Industrial Results obtained with Bessemer Converters having Cylindrical Profiles, Melts of Low Depths and Large Diameter Bottoms. M. Gombert and J. de Hedouville. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sc. 1, 1–9). Results are reported of trials initiated by IRSID at three Lorraine steel plants with Bessemer converters showing various modifications in shape and size. Converters of cylindrical shape, with large diameter bottoms of high blowing capacity, are claimed to give rapid conversions and increased bottom life.—E. C.

The Basic Bessemer Conversion Process. P. Coheur. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Oct., 484–497). A variety of techniques for steel refining based on the original Bessemer converter which have been developed in the last 100 years are surveyed. The recent advances in basic Bessemer practice involving the use of oxygen and steam are reviewed: particular importance is paid to the manufacture of steels having good cold working properties. (61 references).—B. G. B.

Hydrogen in Liquid Basic Bessemer Steels. A. Decker and R. Sevrèn. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Oct., 522–527). The average hydrogen content in steels in the converter after blowing with oxygen–water vapour is 9·5 cc/100 gms. After addition of a second slag and blowing with air the content is 3 to 5 cc/100 gms. At pouring the hydrogen content is of the order of 3 to 6 cc/100 gms.—B. G. B.

Simultaneous Desulphurization and Deoxidation in the Basic Converter. F. Meunier and C. Soisson. (*Rev. Mét.*, 1955, **52**, No. 8, 589–595). The authors recall briefly the fundamentals of their process for improving high grade killed steels in the basic converter. Experimental results have shown that desulphurization and deoxidation of steels by basic slags is due to simultaneous reactions controlled by the equilibrium reaction between sulphur and oxygen dissolved in the metal and between their ions in the slag. Desulphurization is more closely related to the activity of oxygen dissolved in the metal than to slag basicity.—G. E. D.

"Hot Cooling" of O.H. Furnaces. A. I. Tyurin, F. G. Rostovshchikov, V. D. Trebukhin, S. A. Chervonnyĭ, N. A. Vecher, and I. K. Skorichenko. (*Stal'*, 1955, (3), 278–281). [In Russian]. The system of O.H. furnace cooling in which the water is largely converted to steam is critically considered and compared with a system in which the water leaves the furnace mainly as hot water which is used e.g. for space-heating. The latter system is considered in detail and test results from an experimental installation are presented. These show that the system is cheap to instal, easy to maintain and does not affect furnace operation. The further possibilities of the method are discussed.—S. K.

Mixed Roofs for O.H. Furnaces. N. A. Ivin. (*Stal'*, 1955, (3), 224–226). [In Russian]. Trials are reported in which various combined arrangements of Dinas and chrome-magnesite bricks were used in O.H. furnace roofs with the object of economically preventing local wear. It was found that such mixed roofs enabled the stability of the roof to be increased by 35–40% and over with a comparatively small expenditure of chrome-magnesite bricks. For the particular furnace-conditions studied (at the Frunze Works) chrome-magnesite was best used in the form of inter-bedded panels 700–900 mm wide along the back and front walls.—S. K.

Improvements in the Design of O.H. Furnaces. M. A. Chernenko. (*Stal'*, 1955, (3), 226–237). [In Russian]. This is a detailed review of the best O.H. practice in the U.S.S.R. and of recommended improvements. It is based on answers to questionnaires, information from research organizations, and previous planning experiences. The mean charge weight is given as about 180 t and the relation between rate of production and charge weight is plotted for American, German, and Soviet furnaces. 55% of these furnaces worked on mixed gas, 29% on oil, and 16% on producer gas and combined fuel. A section is devoted to the principal dimensions of the furnace working-space, with comparisons of Soviet and foreign practice. The great majority of Soviet furnaces have improved Venturi-type ports. Sections are devoted to slag-pockets, regenerators, valves, and stacks. Finally new types of steelmaking furnaces are briefly considered, and the importance of developing massive furnaces for working with oxygen is indicated.—S. K.

Increasing the Stability of Tilting Open-Hearth Furnaces. V. V. Leporskiĭ and V. A. Tyagus. (*Stal'*, 1955, (8), 704–708). [In Russian]. An account is given of the investigation and reconstruction of those parts of tilting O.H. furnaces which had been found to wear out comparatively rapidly when working on pig iron containing 1·4–1·6% P. With such irons roofs of high-density magnesite-chromite brick were essential. The possibility of using a simplified front-wall construction on tilting furnaces was confirmed. A modification of supporting-girder design for cooling with sea-water is proposed. Further research on these furnaces is urged, particularly on methods of removing slag from slag-traps during operation.

Practical Problems in the Oxygen Steel Melting Process. O. Cuscoleca and K. Rösner. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sc. 6, 1–15). A detailed description is given of principles and practice of this process of steel refining, based on blowing a converter with pure oxygen. Chemical problems are discussed and attention is given to details of converter design and maintenance. The process creates considerable smoke and dust problems and trials with various types of dust extractors and precipitators are reported.—E. C.

Characteristics and Production Data of Large Present-Day Bessemer Converters. G. Decamps. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sc. 5, 1–5). A summary account is given of data, products, and operational experience obtained in Lorraine with three large Bessemer converters of new design, as developed by IRSID. Great satisfaction is expressed in respect of quality of products, performance of the converters and reduction in operating costs.—E. C.

Oxygen Converter Process. G. B. McMeans. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 163–169). The author describes the "L–D" oxygen steelmaking process, and discusses its economic advantages. The quality of the steel produced is also considered.—G. F.

LD-Process of Steelmaking with Oxygen Jet. H. Trenkler and H. F. Hauttmann. (*Metal Progress*, 1956, **69**, Jan., 49–56). A description of this process is given together with details of the satisfactory results obtained at Linz in Austria. Oxygen of 98% purity is blown vertically downward by a water-cooled nozzle on a bath of hot metal. The process has a high thermal efficiency (70–75%). The manufacturing cost of LD steel is 55% that of open hearth steel. Over 1,000,000 tons of rimming and fully killed steel, mostly for wire drawing, deep drawing sheets and thin plates have been produced at Linz.—B. G. B.

Excessive Oxidation of Iron in the Bessemer Converter: Causes and Methods of Avoiding It. P. Krynicky. (*Bol. Assoc. Brasil Met.*, 1955, **11**, July, 349–366). [In Portuguese]. Figures quoted for the 10-ton acid converter production at the Usina Acesita in 1952 show melting losses above the customary average. The author investigated this problem by making a series of controlled trials and reports on these, giving full data, in conjunction with a description of the physical chemistry of the process. It is recommended that the mixer should be run at 1335–1345° C, that production be organized to be as continuous as possible, and that scrap, if required, be added in the second period in order to reduce oxidation losses. (13 references).—P. S.

Use of Oxygen for Acceleration of Refining in Steelmaking. H. Kosmider. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1433–1439). The author deals with the oxygen requirement for oxidation and with the heat evolved in these processes. He refers to the blowing time and rapidity of conversion in relation to oxygen supply and oxygen concentration in the air blast. Rate of decarburization, reduction of refining time, and the effects of additives are discussed.—A. C.

Operation of Basic-Bessemer Converters. (*Found. Trade J.*, 1955, **99**, Dec. 29, 775–776). A summary is given of recent French work on the factors which contribute to uniformity of composition of metal produced in the basic-Bessmer converter. It is concluded that providing uniform charges of metal, lime, and ore are used, the process may be closely

controlled by continuously measuring the volume of the blast, the bath temperature and the quantity of oxygen which has passed through the bath.—B. C. W.

Contribution to the Study of Factors in Steelmaking which Influence Results Furnished by the Galey Opacimeter. M. Gombert. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (12), 2389–2402). With a view to studying the influence of temperature and quantity of lime added on the phosphorus content of the metal and iron content of the slag at the moment of maximum opacity of the fumes during dephosphorization in the converter, 31 blows were followed. Lime added and the temperature at which the converter was burned down were varied systematically. Results are given and discussed.—T. E. D.

Characteristics of the Temperature Curves at the End of Dephosphorisation. B. Trentini. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1955, **12**, (12), 2379–2387). The manner in which the temperature tails off in a converter at the end of dephosphorization is correlated with phosphorus and manganese contents of the metal and iron oxide content of the slag. Practical applications of this knowledge are suggested.

Flame Studies in Open Hearth Furnaces. M. A. Glinkov. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 6, 1–28). A detailed survey reviews the development and present state of knowledge in the Soviet Union in the field of research into gas flow, flame properties, and heat transfer in open hearth furnaces. Covering theoretical, model, and full-scale investigations the survey is subdivided under the headings: methods of research, principles of heat exchange in the fusion zone, aerodynamics of flames, processes of combustion in flame jets, flame radiation, trends for improving open hearth furnace burners. (21 references to Russian literature).—E. C.

A Study of the Flow of Gases in Open Hearth Furnaces, Using Reduced-Scale Models. F. Husson, R. Durand, and G. Cohen de Lara. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 5, 1–24). A detailed report is made on the first portion of a comprehensive series of model studies of gas flow in conventional open hearth furnaces and also in a Terni type of furnace. The work follows investigations carried out by B.I.S.R.A. in Britain, but gases of lower calorific value are used.—E. C.

The Terni-Type Open Hearth Furnace. A. Rossin. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 4, 1–11). An account is given of the principles, construction, and performance of the Terni type open hearth furnace. Operating data and economics are discussed.—E. C.

Present State of Open-Hearth Furnace Automation at The Novo-Tagil' Metallurgical Works. I. N. Mikhailov. (*Stal'*, 1955, (5), 417–425). [In Russian]. The O.H. furnaces at Novo-Tagil' work the ore-scrap process with the addition of about 70% of liquid pig-iron, the fuel being mixed blast-furnace and coke-oven gas and coal tar. The present article describes the automatic control of combustion, of pressure in the working space of the furnace, of the distribution of combustion products between the air- and gas-regenerators and of valve operation. Furnace instrumentation in general is also considered, the need for a roof-temperature measuring device more reliable than optical pyrometers being indicated.

Efforts to Prevent the Formation of Hot Spots on O.H. Furnace Supporting Girders. S. I. Moiseevich. (*Stal'*, 1955, (5), 425–431). [In Russian]. An account is given of the investigation of a sharp increase in one shop of hot-spot formation in O.H. furnace supporting girders cooled with circulating water. Among the measures taken were: increase of the water-flow by improved piping and pumping; discontinuation of girder repairs by welding during service; adoption of a new, double-chamber girder; use of better steel and production methods for working the girders; slight acidification of the cooling water. Hot-spots were virtually eliminated, but information is not yet sufficient to judge the respective efficacies of these measures.—S. K.

Construction and Equipment of Modern Fixed Siemens-Martin Furnaces. H.-F. Strähuber. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1439–1445). Particulars are given of the 150-ton Maerz furnace. Control and instrumentation are described, and the deliberate avoidance of complete automation is discussed.—A. C.

Advantages of Feeding Open Hearth Furnaces with a Low-Carbon Iron Produced from Scrap in a Hot-Blast Cupola. R. Boutigny and C. Barbazanges. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 10, pp. 1–21). A detailed account is given of the principle, development, and practice of a process now in production in Germany. 100% Scrap is used with a coke consumption of 20% (by weight). The scrap is melted in a cupola with water-cooled shaft, neutral lining, and working with a basic slag. Together with the use of pre-heated air this is claimed to give adequate desulphurization, a sufficiently high temperature of the melt, and continuous economical production.—E. C.

The Development of the Open Hearth Furnace. F. Bartu. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 2, 1–19). Principles of construction and operation of open hearth furnaces are discussed in the light of present European and American practices. Economics are considered in relation to changes in technique and developments in refractories, but purely metallurgical aspects are not discussed.

Performance Problems with Siemens-Martin Furnaces Treating Pig Iron and Scrap. W. Schmitt. (*Stahl u. Eisen*, 1955, **75**, Dec. 1, 1627–1640). The important influences on performance are examined. These are given as charge capacity, hearth capacity, scrap condition, charging method, pig iron charge, previous charge, and heat intensity. The effects of the carbon contents of input and output, the quality of steel, the refining speed and method, the hearth capacity, and the rise in bath temperature are discussed.—A. C.

The Present State of the Treatment and Utilization of Steel Shavings. E. M. Guzev. (*Stal'*, 1955, (7), 639–645). [In Russian]. Present Soviet practice in the treatment and utilization of steel turnings, trimmings, and similar waste products of shaping processes is critically reviewed. After an outline of shortcomings in this field, the granulation of the material is considered, the performances of various types of installation being compared. Methods of sintering and baling are discussed, including cold-pressing and hot-pressing with the charge heated by the passage through it of an electric current. Other aspects considered are furnaces for heating and removal of impurities and the remelting of alloy steel shavings.—S. K.

Loss of Iron in the Slag in the Open-Hearth Process. F. Čechura. (*Hutnické Listy*, 1956, **11**, (2), 86–91). [In Czech]. Iron losses are shown to be least if lime is charged between two layers of ore, and greatest if the bottom layer of ore is omitted. The effects of preheating the charge before admitting the liquid iron were studied. The time of preheating which just leads to a rising of the iron content in the primary slag is best, resulting in the optimum utilization of the manganese in the charge and to more complete dephosphorization. More intense preheating results in increasing iron losses.—P. F.

Hydrogen in Molten Steel. II. S. Sawa. (*Tetsu to Hagane*, 1955, **41**, Nov., 1166–1172). [In Japanese]. Experiments on the rate of H_2 evolution from steel melted in a high-frequency induction furnace are reported. The H content in the steel was decreased when a slag layer was present, and removal of this, with exposure to the atmosphere, caused a rapid decrease. A relationship established by Carney *et al.* between [H] in the steel and P_{H_2O} in the atmosphere was considered inapplicable, due to a different value for P_{H_2O} in the surface layers of the steel. Basic slag allowed H_2O to pass more readily than others. Small Ti additions prevented H_2 from escaping from steel on or after solidification.—K. E. J.

Activity of Oxygen in Liquid Iron. V. V. Averin, A. Yu. Polyakov, and A. M. Samarin. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (3), 90–107). [In Russian]. The temperature dependence of the equilibrium constant of the reaction between liquid iron and a steam–hydrogen mixture, was experimentally determined. It was established that the activity coefficient of oxygen in liquid iron depends on temperature and on the oxidation potential of the gaseous phase. The lack of proportionality between the oxygen concentration in the metal and its activity in the gaseous phase indicates that with increasing oxygen potential of the gaseous phase the valency of iron increases forming an oxide soluble in the metal.—V. G.

The Influence of Phosphorus on the Oxygen Solubility in Molten Iron–Chromium and Iron–Nickel Alloys. N. P. Leventsev and A. M. Samarin. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (5), 133–138). [In Russian]. The influence of chromium and nickel on oxygen activity in metal was investigated. It was found that an increase in the phosphorus content in iron–chromium melts increases oxygen solubility. Temperature has an insignificant effect on oxygen

solubility in iron–chromium–phosphorus melts, and oxidation of phosphorus takes place together with oxidation of chromium. Oxygen solubility in iron–nickel melts increases with increasing phosphorus concentration. The presence of about 1% of nickel in iron containing up to 0·7% of phosphorus decreases the solubility of oxygen. Oxidation of phosphorus and nickel in iron–nickel–phosphorus melts leads to the formation of iron and nickel phosphates in nickel oxide.—V. G.

Production of Electric Steel by a Duplex Process. F. P. Edneral. (*Stal'*, 1955, (5), 439–440). [In Russian]. Recent technical developments, possibly advantageous for the production of steel in electric furnaces from a semi-steel produced in converters or O.H. furnaces are discussed. The use of converters blown with oxygenated air is considered the best solution. A suggested plant lay-out with two 40-ton and three 60-ton furnaces has a converter shop with a mixer and three 20-ton converters (one in use, one in reserve, one under repair) feeding liquid and metal to the three larger furnaces; the smaller furnaces work with solid charges. The operation of this plant under various conditions is briefly considered.—S. K.

Prerefining Very High Silicon Iron with Pure Oxygen in the Ladle. P. Leroy and D. Menendez. (*Publ. Inst. Rech. Sid.*, Series A, 1955, Nov., (118), pp. 25). Prerefining tests, in which oxygen at a pressure of 10 to 15 kg/cm² was blown at the surface of the iron in the presence of a suitable slag were performed on a very high silicon iron (2 to 3% Si) at La Felguera works in Spain. Detailed results on the lowering of the silicon, manganese, and carbon contents, elevation of temperature, and the oxygen balance are quoted.—T. E. D.

Desulphurization of Steel by Soda Ash Treatment. N. J. Wadia, V. G. Paranjpe, and S. Visvanathan. (*Tisco*, 1956, **3**, Jan., 1–4). The results of experiments on the desulphurization of melts of low-carbon steel and high-silicon steel with soda ash, and the effects of varying degrees of deoxidation are presented and discussed in relation to earlier work. It was found that the desulphurizing action of soda ash is increased by prior deoxidation and that the efficiency is very low when compared with that obtained in the treatment of blast-furnace iron. The results also show that the oxygen potential obtained during treatment influences the extent of desulphurization. (11 references).—L. E. W.

10-12 Ton Demag-AEG Electric Furnace at Barcelona. R. Oliva. (*Acero Energ.*, 1955, **12**, Nov.-Dec., 47–50). [In Spanish]. The installation of this furnace at the Material and Constructions Ltd. plant is described. The furnace is 3·8 metres dia., basket-charged, and fitted with 350 mm dia. electrodes. The power sources is a 4,000 kVA transformer and the Leonard-Tinill control system is used.—P. S.

Methods of Calculating Steel-Melting Arc Furnaces. Ya. M. Bokshitskii. (*Stal'*, 1955, (7), 646–647). [In Russian]. Some recent views on the design and rating of steel-making arc furnaces are critically reviewed.—S. K.

Use of Graphite Electrodes in Electric Arc Furnaces. G. Moll. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1445–1452). The significance of graphite electrodes in the development of electric steel production is indicated. Properties are reviewed, and practical considerations in use are discussed at length. Graphite, carbon, and Söderberg electrodes are compared.—A. C.

Automatic Regulation of Arc-Furnace Cooling. P. F. Sabaneev. (*Stal'*, 1955, (7), 612–616). [In Russian]. Observations on the water-cooling of steel-melting arc furnaces are presented and discussed. An automatic system of water-flow control was developed which reduced water consumption at the furnace by 50–55%, the total saving being raised to 60–65% by dispensing with unnecessary cooling. The regulator normally works without maintenance for 1–1·5 years.

On the Binderless Dolomite Furnace Building of Basic Electric Arc Furnace. H. Odazima and Y. Kawamoto. (*Sumitomo Metals*, 1955, **7**, July, 167–174). [In Japanese]. A review is made of the method of building basic electric furnaces with hearth and walls of rammed dead-burnt dolomite, no binder being used. It is concluded that the rigid construction can lead to higher refining temperature and improved steel quality; that hearths last almost indefinitely, and that substantial cost reductions per ton of steel can be achieved.—K. E. J.

The Influence of Blowing With Carbon Monoxide on the Quality of Steel Produced in Electric Furnaces. A. V. Vishnyakov and A. M. Samarin. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (3), 102–109). [In Russian]. The possibility of purification of liquid steel from hydrogen and nitrogen by blowing with carbon monoxide was investigated. It was established that such a treatment of liquid steel in an arc furnace under a deoxidizing slag considerably decreases its nitrogen and hydrogen contents and speeds up the desulphurization and diffusion deoxidation processes. A considerable saving in ore, fluxes, and power used can be achieved.—V. G.

Electrical Steels. P. H. Estes. (*Canad. Min. Met. Bull.*, 1956, **49**, Feb., 82–86). There has been a change in the types of lamination materials used. Ten years ago hot-rolled sheet (0·25 to 4·5% Si) was used almost exclusively. Now this material represents only 40% of the purchased tonnage, 20% being cold-reduced silicon strip (non-orientated), 20% being orientated strip, and 20% being common iron. The characteristics of the materials are examined, and the relative advantages from the application standpoint are discussed.

The Zone Melting Method and Its Application. R. Graf. (*Métaux Corrosion–Indust.*, 1955, **30**, Dec., 463–475). A review of the principles of this technique and its limitations is presented. A brief mention is made of the purification of iron to obtain a material having very soft magnetic properties.

An Investigation of Properties of Individual Components of Molten Slag Using Electromotive Force Measurements. O. A. Esin and B. M. Lipinskikh. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (2), 60–66). [In Russian]. E.m.f. of concentration cells (without transfer) made of slags containing various concentrations of CaO, MgO, Al_2O_3 and SiO_2 at 1470° C were measured. On the basis of the results obtained, activities of (CaO + MgO), Al_2O_3 and SiO_2 were calculated, as well as measurements of changes of isobar potential of individual components on dilution were carried out. Amphoteric character of alumina was demonstrated and the presence in the liquid slag of anions of compounds Ca_2SiO_4, $CaSiO_3$, $Ca_5Al_6O_{14}$ and $Ca_2Al_2SiO_7$ was confirmed. On an example of the determination of silica content, the possibility of using the above method for the control of the composition of liquid slag in steel making furnaces was shown.—V. G.

The Limits of Dephosphorisation of Iron by Lime. G. Trömel and W. Oelsen. (*Arch. Eisenhüttenwesen*, 1955, **26**, Sept., 497–506). The authors discuss the equilibrium diagram for iron, phosphorus, oxygen and lime, and the experimental technique for its determination. The effect of slag on phosphorus-content is examined, and the influence of temperature is indicated.—A. G.

Reactions between Iron–Manganese Melts and Molten Aluminates. W. Oelsen and G. Heynert. (*Arch. Eisenhüttenwesen*, 1955, **26**, Oct., 567–575). The authors review unsolved problems of the manganese reaction in slightly diluted slag. Experimental results are given for the reaction of liquid iron with iron–manganese oxides in an alumina crucible. The equilibrium of the liquid iron with very small manganese content is discussed, and the combination of inclusions in the case of small manganese content is compared with the combination occurring in slag. Saturation limits for alumina and aluminates in the slag are indicated. Melting points of the aluminates and the equilibrium diagram are given. The determination of the equilibria in the system iron–manganese–aluminium–oxygen is discussed.—A. C.

Investigations of the Iron–Iron Oxide–Lime System. G. Trömel, W. Jäger, and E. Schürmann. (*Arch. Eisenhüttenwesen*, 1955, **26**, Nov., 687–700). The authors describe microscopical and X-ray examinations at room temperature, and radiographic observations of reactions at about 1200° under argon and oxygen, or under vacuum. The mixture of iron oxide and lime was melted in an iron crucible, and crystallization observed. The results of the various investigations are comprehensively discussed.—A. C.

Comments on the Shape of Ingots. Square Ingots from Electric Steelworks and Flat Ingots from Open-Hearth Steelworks. J. Duflot. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 3, 569–603). The shape of ingots is discussed and casting practice in France is compared with that in other countries. Details of performance with different shape moulds, various feeder heads, hot-tops etc., and bottom poured moulds are surveyed. The effect of the relation between ingot weight and mould weight is also mentioned.—T. E. D.

An Investigation of the Limiting Stages in the Desulphurization of Molten Iron with Slag. O. A. Esin and V. N. Shikhov. (*Izvest. Akad. Nauk, SSSR, Otdelenie Tekn. Nauk*, 1955, (2), 105–112). [In Russian]. Kinetics of the desulphurisation process of iron with acid, neutral, and basic slags of the

$CaO–SiO_2–Al_2O_3–MgO$ system at various sulphur concentrations (from 0·005 to 0·1%) in the metal were investigated using radioactive sulphur. It was found that the velocity of desulphurisation is directly proportional to the boundary surface between iron and slag. A comparatively small increase in temperature (60–100° C) increases the velocity of desulphurisation with basic slag by a factor of 1·5–2 while the transfer of sulphur to acid slag is considerably increased (10 times or more). The order of desulphurisation reaction with basic slag was found to be unity and that with an acid slag—0·75. Analysis of the data obtained indicated that the factor limiting the velocity of desulphurisation of metal by a basic slag is the coefficient of diffusion of sulphur in slag phase, and by an acid slag the chemical reaction itself.—V. G.

Some Problems of the Theory of Slags. I. S. Kulikov. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (2), 113–121). [In Russian]. Deficiences of the ionic theory of slags are discussed. It is pointed out that the purpose of the theory of real solutions when mathematically calculating activities of effective concentrations is to take into consideration a number of physico-chemical phenomena like heat of mixing, formation of chemical bonds of the covalent type, polymerisation, etc. An attempted thermodynamic analysis of the $FeO–SiO_2$ system is given. Despite many assumptions, a good agreement between calculated and experimental data (like activities of FeO partial heat of solution of FeO in the $FeO–SiO_2$ system) was obtained.

Bottom Pouring without Solidification during the Filling of the Head. N. I. Shutkin. (*Stal'*, 1955, (7), 607–611). [In Russian]. The reasons for the penetration of shrinkage cavities into the body of steel ingots are discussed and a new variant of bottom pouring is described by which this is prevented. In this the solidification of the metal during the filling of the head is prevented. The new procedure has the same effect on the position of shrinkage cavities in the heads as an increase of head volume, it decreases contamination by non-metallic inclusions and facilitates the detection of ingots with normal distribution of shrinkage cavities.—S. K.

Energetical Theory of Crack-Formation in Cast-Iron Moulds. S. F. Fomin. (*Stal'*, 1955, (8), 743–747). [In Russian]. The author develops a theory of the cracking of cast-iron moulds attributed to the storage in the metal of excessive amounts of potential energy. The influence of various elements and other factors on energy-storage is discussed. An editorial note indicates the need for verification of the views advanced.—S. K.

On the Making of Small Rimming Steel Ingot. I. S. Yama and K. Nagami. (*Sumitomo Metals*, 1955, **7**, July, 175–185). [In Japanese]. Rimming steel was experimentally produced in 450 kg ingots, for cold-drawn bar, etc. The relationships between teeming rate and temp. and skin thickness were investigated. The properties of the rolled products were satisfactory.—K. E. J.

Out Goes Hydrogen. (*Steel*, 1955, **137**, Nov. 14, 120–123). The position of vacuum degassing of tonnage steel in Germany, and its introduction into the U.S. are discussed.

New Hot Tops Save Metal, Make Sounder Ingots. H. D. Shephard. (*Iron Age*, 1955, **176**, Nov. 24, 79–82). The use of " Foseco Feedex " exothermic hot tops for a variety of steels in 4–20½ inch square moulds is described. Pressed or rammed to shape, the exothermic material burns to form a solid insulating refractory at 3500° F. Metal loss is cut from 12–16% to 4–8%.—D. L. C. P.

Electricity Now Being Employed for Hot-Topping. F. Nicholson. (*Blast Furn. Steel Plant*, 1956, **44**, Jan., 75–78). The technique described involves the striking of an arc between a movable electrode and the top of the ingot to maintain the top temperature in order to cool the ingot from the bottom and inwards from the sides.—B. G. B.

The Influence of the Temperature of Liquid Steel On Ingot Structure. A. P. Pronov. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (4), 58–62). [In Russian]. Factors affecting the structure of ingots during their solidification in ingot moulds and in particular the temperature of steel are discussed.—V. G.

Hot Tops. (*Brit. Steelmaker*, 1955, **21**, Dec., 404–405). A description is given of the " C. & D." hot-top made available in Britain by the London and Scandinavian Metallurgical Co. Ltd. Its main features are that it is re-usable, adjustable in the mould to give varying ingot lengths, and fully floating to minimise hanger cracks.—G. F.

Study of Basic Bessemer Rimming Steel Ingots. A. Delsa, M. Nepper, F. Classen and J. Nils. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Oct., 498–521). The results of investigations into soundness of this type of steel ingot are reported. Factors affecting the oxygen content are examined and the effect of anthracite, manganese, and aluminium additions to the metal have been studied. Liquid and solid ferromanganese and calcium silicide additions have also been studied and the results examined statistically. The product of % C × % O is shown to be of great importance as measured in the middle and at the top of the ingot.—B. G. B.

PRODUCTION OF FERRO-ALLOYS

The Viscosity of Primary and Final Slags During Smelting Ferroalloys in a Blast Furnace. N. L. Zhilo and L. M. Tsylev. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (10), 90–106). [In Russian.] Results of a study of the viscosity of primary and final slags during the production of ferromanganese, ferro-silicon and silicon manganese are described Samples of primary slags were taken mainly from the peripheral zone of middle and bottom level of the stack, from the bosh and from the tuyere level. On the basis of result obtained, optimum compositions of slags from the point of view of their melting point and viscosity were established.

Study of Iron-Chromium Alloys in the Neighbourhood of Equiatomic Composition. G. Pomey. (*Publ. Inst. Rech. Sid.*, Series A, 1955, Nov., (117), 165 pp.). Choice of materials and preparation of one series of 8 alloys, covering a wide range of compositions, and another series of 7 alloys, with compositions in the equiatomic region, are described. The properties of the alloys in the α solid solution phase are examined, with a study of the order—disorder transformation in the equiatomic composition region. Finally the $\alpha \rightleftharpoons \sigma$ transformation is studied by a number of methods. Many photographs are shown. (61 references).—T. E. D.

Properties of Some Tungsten and Titanium Steels Containing Boron. A. Bannerjee, D. K. Sood and P. Mehta. (*Tisco*, 1956, **3**, April, 53–62). Boron steels containing 1·4–1·6% W exhibit high-strength properties similar to molybdenum–boron steels. The amount of tungsten required to obtain an equivalent increase in strength is more than twice the amount of molybdenum needed. The titanium–boron steels show no strength increase at the conventional normalizing temperature owing probably to the stability of titanium carbide. By normalizing at 1100° C, however, an increase in strength is obtained for the titanium–boron steel with 0·38% Ti. A gradual decrease in the yield/tensile ratio occurs in a boron steel with over 0·6% Mo. Precipitation hardening occurs in molybdenum–boron steels after suitable solution treatments. Reeve weldability tests showed that the experimental boron steels containing tungsten and titanium were comparable to Fortiweld in their weld-cracking resistance. (25 references).—L. E. W.

Transformer Steel Alloyed with Aluminium. N. F. Dubrov, V. A. Selivanova and T. S. Konovalova. (*Stal'*, 1955, (4), 347–350). [In Russian]. The steel which is used in the form of 0·5 mm thick sheet was produced in arc furnaces, the aluminium being added after the renewal of the oxidizing slag. Specimens with aluminium contents of 0·02–0·14% were subjected to magnetic and bending tests and to grain size determinations. The addition of aluminium was found to increase the ferrite grain-size and decrease core losses, 0·08–0·12% being the optimal content for 0·5 mm sheet. The scheme of aluminium alloying recommended has been successfully adopted in works practice.—S. K.

The Production of Ferromanganese using Chiatursk Carbonate Manganese Ores. A. Yu. Arsenishvilil, S. G. Boiko, M. A. Kekelidze, V. V. Perova, B. F. Filonenko and A. N. Tsaritsyn. (*Izvest. Akad. Nauk SSSR, O.T.N.* 1955, **11**, 5–12). [In Russian]. A short description of Chiatursk carbonate manganese ores is given. Experimental production of ferromanganese from burdens containing them is described. The results obtained indicated that the ore has a beneficial influence on furnace operation and can be used successfully for the production of ferromanganese.—V. G.

New Carburizing Steels for Critical Gearing. R. S. Archer, V. A. Crosby, and G. A. Timmons. (*Iron Age*, 1956, **177**, Feb. 9, 92–95; Feb. 23, 96–100). An account is given of a new series of carburizing steels with molybdenum as chief

alloying element. They can be quenched directly from carburizing; retained austenite is not a problem. They combine high case hardness with optimum wear resistance and are showing benefits in the production line and in gear performance tests.—D. L. C. P.

FOUNDRY PRACTICE

Progress of Iron and Steel Casting Industry in Japan. H. Tanimura. (*Tetzu to Hagane*, 1955, **41,** July, 770–776). [In Japanese]. Progress since 1946 has largely depended on pre-war and wartime research work, which is surveyed. (43 references).—K. E. J.

Foundry Problems and Principles. G. J. Rogers. (*Found. Trade J.*, 1955, **98,** May 19, 531–539). A series of practical foundry problems, mainly connected with non-ferrous alloys, are illustrated and discussed to bring out the important basic principles of foundry work.—B. C. W.

The Particular Properties of the Cast Metals Used in the Automobile Industry. Ferrous Metals. G. Iungmann. (*Fonderie*, 1955, July, 4595–4599). Cast metals used in the automobile industry must be capable of withstanding static loads, impact loading and frictional wear. Under these three headings the requirements imposed on the various parts of an automobile are reviewed together with the metallurgical solutions which have been adopted in each case.—B. C. W.

Metallurgical Study of Grey Iron Castings. G. Cola. (*Fonderia Ital.*, 1955, **4,** Sept., 425–452). [In Italian]. After a general review of the structural properties of cast iron, the author makes a close study of all the factors which influence quality and discusses the best means of ensuring that castings come up to standard. Results of comparative tests between Italian and Swedish specimens are given and the relation between the casting and the standard bar properties is studied. Numerous microphotographs and tables are given. (51 references).—M. D. J. B.

Metallurgical Testing of Grey Iron Castings. G. Cola. (*Ing. Mecc.*, 1955, **4,** Sept., 17–48). [In Italian]. In this paper the author discusses cast iron structure with particular reference to the kinetics of solidification. The mechanical properties of different samples are considered. These are examined by the classical methods and by fatigue tests, impact, thermal treatment, wear, corrosion tests, X-rays, ultrasonics, etc. Researches carried out by a commission of Italian foundries are described and comparative tests between Italian and Swedish specimens and the relations between casting and standard bar properties are discussed. Numerous diagrams and microphotographs are given. (51 references).—M. D. J. B.

Activity Sampling—Two Case Studies. A. W. Syme. (*Metalworking Production*, 1955, **99,** Dec. 23, 2163–2168). Production of two foundries was recently surveyed using the activity sampling technique. Each survey lasted only a few days, and showed how considerable increases could be made in productive efficiency by better balancing of operations.

Additional Oil Firing in the Cupola. H. Kühne. (*Giessereitechn.*, 1955, **1,** Dec., 240–242). The plant used is described ; results of tests with combined coke and oil firing are reported; its effects on chemical composition and on thermal efficiency are enumerated.—L. J. L.

Experiences with the Metallurgical Hot-Blast Cupola in the Foundry. W. Heinrichs and W. Brüker. (*Techn. Mitt. Krupp*, 1955, **13,** Oct., 122–132). The metallurgical advantages of a hot blast cupola are described, and the paper by Fleming, Interrelation between Combustion and Metallurgical Reactions in the Cupola (*Foundry Trade J.*, 1953, **95,** pp. 349/58, 401/05) is discussed in relation to work done by Krupps using basic slags and a neutral lined cupola. The paper concludes with a description of the plant and operational details. The hearth is lined with carbon, and the upper part of the cupola is lined with firebrick. Experiments are being carried out with a view to continuous operation.

Some Experiments on the Production of Nodular Cast Iron. S. N. Anant Narayan and S. Visvanathan. (*Tisco*, 1956, **3,** April, 48–52). The authors describe some attempts to evolve new procedures for the production of nodular cast iron. The introduction of magnesium in the vapour state by reduction from high-magnesia slags in contact with molten iron and the use of calcium and barium salts as nodularizing agents were investigated. These methods showed no commercial possibilities. (17 references).—L. E. W.

Deoxidation of Malleable Iron. A. Taub. (*Foundry*, 1955, **83,** Nov., 131–133). Experiments to show the influence of different methods of adding aluminium to cupola metal on graphitization of cast iron are reported and discussed. Additions to the ladle or at the spout were not satisfactory and the best results were obtained by adding the aluminium with the charge.—B. C. W.

Pearlitic Malleable Iron Stakes Claims to New Jobs for Castings. C. F. Joseph. (*S.A.E.J.*, 1954, **62,** Oct., 71–74). The properties and applications of pearlitic malleable iron are briefly reviewed. The machinability of the material is from 10 to 30% better than steel forgings of the same Brinell hardness. They also possess good wear resistance, excellent finishing quality, and high strength characteristics.—P. M. C.

New Trends and Achievements in the Production of Malleable Cast Iron. J. Piaskowski and J. Raczka. (*Przegląd Odlewnictwa*, 1955, **5,** (7–8), 209–219). [In Polish]. A review of literature is given. 96 references.—V. G.

Aspects of Corrosion Resisting Steel Castings. W. G. Boustred Jun. (Inst. Brit. Foundrymen (S.A.): *Engineer Foundryman*, 1955, **20,** Nov., 40–43). The metallurgy and foundry practice of stainless alloys containing chromium and nickel are briefly given.—A. D. H.

Aspects of Steelfoundry Practice. H. Hart. (*Found. Trade J.*, 1955, **98,** June 9, 615–620; June 16, 645–653). Various techniques for gating and running steel castings are reviewed, and the formation and methods for avoiding scabbing and porosity are discussed.—B. C. W.

Shell-Moulded Castings Will Affect Shop Practice. O. W. Winter. (*Metalworking Production*, 1955, **99,** Dec. 30, 2227–2230). A comparison is made between normal casting and shell moulding with regard to shop layout, and the machining operations required for castings of up to 50 lbs. It is shown that with proper automatic equipment, shell-mould production costs can be very low, while product quality remains high.—M. A. K.

Characteristics of Investment Casting Alloys. W. W. Lamb and W. F. Carn. (*Machine Design*, 1955, **27,** Dec., 209–210). Ratings of castability of approximately 100 representative alloys, and detailed information on the properties of 26 typical investment casting alloys are given in tabulated form.—M. A. K.

The Physico-Chemical Properties of Some New Zealand Bentonites. F. R. Gordon, J. Rogers, B. Russell and L. C. Trewern. (*New Zealand J. Sci. Tech.*, 1955, **37,** Sept., 132–141). Tests carried out on samples of bentonite using differential thermal analysis, X-ray and petrological techniques are described. The properties of New Zealand bentonites are compared with those of the U.S.A.—B. G. B.

Investigations on the Measurement of the Plasticity of Non-Consolidated Mould Sand. H. Siegel. (*Giesserei*, 1955, **42,** Dec. 8, 686–691). A so-called plastograph is described which is an instrument designed to measure and record the amount of work necessary to knead sand. The experimental method is described and numerous results given, which include the effect of moisture content on the kneading work for different bentonites and quartz sands. From these results the plastic behaviour of the moulding sand can be deduced.

Sand Drying Plant for CO_2 Sand. W. Sander. (*Giessereitechn.*, 1955, **1,** Dec., 243–244). A drying plant for quartz sand which has been working satisfactorily for 6 months without requiring major repairs is described and illustrated.

Risering of Grey Iron Castings. Progress Report No. 6. E. J. Sullivan Jun., C. M. Adams and H. F. Taylor. (*Trans. Amer. Found. Soc.*, 1955, **63,** 8–12). Experimental results on the effects of carbon, silicon, sulphur, phosphorus, and manganese on the shrinkage of grey cast iron are briefly reported. They are discussed in relation to graphite structure and mould dilation.—B. C. W.

Risering Requirements of Nodular Iron. R. C. Shnay. (*Trans. Amer. Found. Soc.*, 1955, **63,** 293–294). The risering requirements of nodular iron are illustrated by radiographs of plate castings in grey iron, steel, and nodular iron.—B. C. W.

Principles Applicable to Vertical Gating. K. R. Grube and J. G. Kura. (*Trans. Amer. Found. Soc.*, 1955, **63,** 35–48). The results are presented of an investigation into the design of a vertical gating system for vertical plate castings. The flow through the gating system was studied by photographing the flow of water in transparent plastic moulds and the results were confirmed by radiography of aluminium alloy castings. Among the factors studied were the effect of sprue length and

taper, the design of the runner and runner extension, the design of the gate and the design of the side riser and web.

Calculation of Feeder Heads. P. Ma. Iñarrairaegui. (*Met. Elect.*, 1955, **19**, Jul., 49–56; Aug., 41–49). [In Spanish]. The use of exothermic materials, chills, open, semi-blind, blind, and pressure feeder heads is discussed in relation to their controlling effect upon solidification rates and feeding in order to produce sound castings. Methods for the calculation of the shape and size of feeder heads and exothermic pencils are described and applied to the design of a mould for a wheel casting.—P. S.

Water-Cooled Cupola Brightens Future For Consistent Control of Castings. L. H. Wisner. (*Western Metals*, 1955, **13**, July, 52–54). The Meehanite " Equiblast " water-cooled cupola is described. In this cupola the contour and diameter of the refractory lining and therefore the oxygen and temperature distribution remain constant. A cleaner, purer, and mechanically superior metal is produced. The manufacture of GS and GSF " Ductiliron " Meehanite in this new type cupola are described.—P. M. C.

Development of an Improved Method for Cupola Charging to Meet Increased Production Requirements. H. G. McCallum. (*Gen. Motors Eng. J.*, 1955, **2**, Nov.-Dec., 14–19). A description is given of the original system followed by a detailed account of the new system, which utilizes electromagnetic charge make-up equipment and skip chargers with cone-bottom-type charging buckets.—E. A. C.

A Guide to the Formulation of Coke Consumption Schedules for Cupolas. H. Koppe. (*Giesserei Techn.*, 1955, **1**, Nov., 215–217). A practical method of determining correct coke consumption is briefly described.—L. J. L.

Comparative Studies on Melting Furnaces for the Iron Foundry. B. Marinček. (*Giesserei*, 1956, **43**, Jan. 5, 2–8). The development in the cost per calorie over the past 20 years when produced electrically and when produced from coke is followed. The various factors which affect the quality of the cast iron in the fluid state are discussed and illustrated graphically. The melting process in the iron foundry is then described for the following furnaces: the cold blast cupola, the hot blast cupola, the electric-arc furnace, and the induction furnace. Melting costs for these furnaces are then described and compared.—R. J. W.

The Applications of Ni-Hard Type White Martensitic Cast Irons. (*Rev. Nickel*, 1955, **21**, July-Aug.-Sept., 66–70; Oct.-Nov.-Dec., 96–99). Chemical composition and mechanical properties of two types of Ni-Hard are tabulated. Applications in the cement industry, coal and coke industry, building and public works, dredging, food industry, ore-mining and treatment, and the steel industry are given and illustrated.—T. E. D.

Effects of Physical Environment on Cast-Iron Pipe. A. Baracos, W. D. Hurst, and R. F. Legget. (*J. Amer. Water Works Assoc.*, 1955, **47**, Dec., 1195–1206). The results of a study of the failures in service of cast iron and steam cured asbestos cement pipes carrying water in the Winnipeg and western Canadian districts are described. Iron pipes have failed through transverse cracking. The cause of failure is differential soil movements which result from changes in moisture of the clay soil and can be traced back to the filling-in operation.—B. G. B.

Progress in Special Foundry Irons and their Applications in the Mineral Industry. G. Henon. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 14, 1–12). Various special types of cast irons and steels are described. Specific applications are discussed involving resistance to water, abrasion, corrosion, or raised temperatures.—E. C.

The Improvement in Properties of Molten Iron. II. T. Tottori. (*Tetsu to Hagane*, 1956, **42**, Jan., 3–8). [In Japanese]. Blowing of reducing gases, e.g. H_2 and producer gas, into molten iron increased fluidity and accelerated precipitation of flaky graphite. Blowing of N_2, air, and CO_2 into blast-furnace iron decreased the fluidity; blowing of O_2 reduced impurities such as titanium and vanadium, and improved mechanical properties. Cast iron from charcoal iron was more easily nodulized by magnesium treatment after blowing H_2 or producer gas, whereas that from blast-furnace iron benefited from oxygen blowing. (12 references).—K. E. J.

Growth of Graphite in Grown Cast Iron. E. Matuyama. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 208–211). A slit-type X-ray powder diffraction camera was used to study graphite in cast iron grown by repeated heating in high vacuum. The intensity ratio of the 1011 and 1010 lines increased with the number of heating cycles, indicating more perfect crystal formation. The causes of porosity in the iron are successive spreading and heaping of characteristic crystal grains on the flake surface.—K. E. J.

Master Alloys in the Foundry. J. B. Forster. (*Castings*, 1955, **1**, Dec., 5, 7). The compositions and uses are briefly summarized.—B. C. W.

Metal Temperature and the Iron Melting Reverberatory Furnace. C. G. De Lanal. (*Foundry*, 1955, **83**, Oct., 164, 167–168). The practical methods for improving the heat transfer to the liquid metal bath in a reverberatory furnace are reviewed. The factors considered are burner angle, internal furnace pressure, refractories, and slag requirements.

Quenching, Alloying, and Surface-Hardening of Grey and Malleable Cast Irons. O. Morávek. (*Slévárenství*, 1956, **4**, (1), 16–19). [In Czech]. The heat-treatment, sulphating, and nitriding processes are discussed with a view to the possibilities of producing and designing high-grade castings economically.

Research on Iron Treated with Magnesium Nitride. I. On the Spheroidization of Graphite in Iron. R. Yoda. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 250–255). [In Japanese]. By adding Mg_3N_2 instead of magnesium to iron, both deoxidation and desulphurization as well as alloying of magnesium are achieved. Spheroidization was readily obtained with additions of 1% or more. The danger of explosion of the melt is completely removed, and other elements besides magnesium are not introduced. (27 references).—K. E. J.

Hardenability of Ductile Cast Iron. C. C. Reynolds, W. T. Whittington, and H. F. Taylor. (*Trans. Amer. Found. Soc.*, 1955, **63**, 116–122). Results to show the effects of austenitizing temperature, soaking time, and composition on the hardenability of ductile cast iron are presented and a method is given for calculating hardenability from chemical composition. The relations between section size hardenability and severity of quench are also derived.—B. C. W.

On the Mean Stress Level in the Metallic Matrices of Some Ferrous Materials which Contain Nodular or Lamellar Graphite. W. Grundig. (*Bol. Assoc. Brasil Met.*, 1955, **11**, July, 325–348). [In Portuguese]. A study is made of the way in which elastic stresses are distributed in a variety of graphitic irons. The material is considered as a combination of a metallic matrix and the graphite; it is indicated that the elastic stresses are distributed uniformly through the matrix, the stress level depending on the quantity and shape of the graphite present. This stress, $\sigma_{mat.}$, can be obtained from the relationship $\sigma_{mat.} = E/E_0 \cdot \sigma$, where σ is the nominal stress, E_0 and E the moduli of elasticity of the material as a whole and that of the metallic matrix, respectively. Formulæ are given which enable the relationship $\sigma_{mat.}/\sigma$ to be calculated with respect to the graphite content and form (the restrictor factor). For example, in an iron containing 3% graphite in lamellar form the mean stress level is 160% higher than the nominal stress, in the nodular form it is 25% higher. (23 references).—P. S.

Anti-friction Properties of Spheroidal Graphite Cast Iron. (*Found. Trade J.*, 1955, **99**, Dec. 22, 743–744). A brief summary is given of recent Russian research comparing the anti-friction properties of spheroidal-graphite cast iron with those of bronze, grey iron, and a wrought Ti–Mn iron.—B. C. W.

On Nuclei and Nucleating Materials in Metallic Melts. E. Scheil. (*Giesserei*, 1956, **43**, Jan. 19, 33–40). The concepts of nuclei, nucleating materials, and the poisoning of such materials are introduced and defined. R. Becker's theory of spontaneous nucleus formation is discussed and illustrated using tin as an example. The similarities between catalysts and nucleating materials are described, as are their differences. Experimental investigations (such as grain refining) on the additions of nucleating materials are described, and the effect of over-heating considered. Finally the technical possibilities of nucleation are reviewed. (43 references).—R. J. W.

Creep of Cast Iron with Globular Graphite. V. S. Ivanova and I. A. Oding. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (7), 89–92). [In Russian]. Creep characteristics of nodular cast iron of a composition C (total) 3·3%, C (combined) 0·19%, Si – 2·5%, Mn – 0·67%, P – 0·21%, and S – 0·02%, were determined at a temperature of 450° C. Its resistance to " growth " was determined by holding a specimen for 200 hours at 500° C. No change in the length of the specimen so treated was observed. It was found that nodular cast iron can be utilized as a structural material for service at high temperatures.—V. G.

Good Commercial Nodular Irons Rival Steel in Strength, Ductility. R. Schneidewind. (*S.A.E.G.*, 1954, **62**, Oct., 94–96). Nodular irons offer attractive properties for automotive parts, the combination of strength and ductility approaching that of steel and being superior to that of malleable and grey irons. The properties and effect of heat treatment on nodular irons are briefly reviewed.—P. M. C.

Heat Treating to Produce Malleable Iron. J. H. Lansing. (*Steel*, 1955, **137**, Dec. 19, 106–110; Dec. 26, 60–62). Types of furnaces and temperature cycles are dealt with, and metallurgy and heat-treating practice. Applications are noted.—D. L. C. P.

Effects of Molybdenum on Stability and High Temperature Properties of Pearlitic Malleable Iron. W. G. Scholze, D. V. Doane, and G. A. Timmons. (*Trans. Amer. Found. Soc.*, 1955, **63**, 251–260). The results are given of an investigation into the effect of molybdenum on the tensile properties and the stability of pearlitic malleable cast iron at 538°, 593°, and 649° C. At these temperatures molybdenum additions from 0·2 to 0·75% were found to retard the rates of softening and secondary graphitization, and to raise the short time tensile properties of the irons. The effect of stabilizing treatments at 649° C on tensile properties at lower temperatures was also determined.—B. C. W.

Some Factors in Production of Clean Steel Castings. C. B. Williams. (*Trans. Amer. Found. Soc.*, 1955, **63**, 687–688). The methods used at the Massillon Steel Casting Co., Massillon, Ohio to produce castings with clean surfaces, are briefly described.—B. C. W.

Manufacture of High-Quality, Pressure-Tight Steel Castings. J. F. Wallace. (*Trans. Amer. Found. Soc.*, 1955, **63**, 693–702). The production of pressure-tight high strength castings in sand moulds is discussed with particular reference to the effects of composition and heat-treatment on the notch-toughness of the cast steels.—B. C. W.

Studies in Cement-Sand Steel Casting Methods. Steel Plating with Cement-Sand. W. Eitel and N. Köppen. (*Giesserei, Technisch-Wissenschaftliche Beihefte*, 1955, May, 761–765). A microscopic investigation is described in which the processes at the contact between the cement-sand mould and the cast steel are clarified. The formation of a porous layer in the mixing zone is described. Details of the softening of the sand mould, of the melting of the cement-sand and of the penetration of the cast steel into the mould are given.—R. J. W.

Cast Steels. J. Lomas. (*Canad. Min. J.*, 1955, **76**, Aug., 54–57; Oct., 80–82; Nov., 76–78). Part I. Types of British steels for castings, and their uses, are tabulated. The various types are discussed broadly. Parts II and III. Nickel–chromium, nickel–chromium–molybdenum, high nickel, corrosion-resistant, heat-resistant steels and austenitic steels are discussed in detail, with particular reference to the austenitic manganese and chromium–nickel (18–8) steels.—T. E. D.

The Sand Bonding Properties of Some New Zealand Bentonites. J. Rogers and B. Russell. (*New Zealand J. Sci. Tech.*, 1955, **37**, Sept., 160–171). Tests carried out to explore the scope and limitations of New Zealand bentonites for foundry use are described. The results indicate that though the bentonites are different from those of the U.S.A. they would be suitable for foundry use.—B. G. B.

Microscopy and Moulding Sands. V. D. Frechette. (*Trans. Amer. Found. Soc.*, 1955, **63**, 710–716). The application of optical microscopy to the study of moulding sands is discussed. The aspects considered include identification of constituent minerals by the polarizing microscope, quantitative analysis in terms of minerals, particle size distribution, and void shape and distribution.—B. C. W.

Load Carrying Power of Moulding Sands. H. W. Dietert, F. S. Brewster, and A. L. Graham. (*Trans. Amer. Found. Soc.*, 1955, **63**, 642–649). Results are presented to show the effects of moisture, percentage bond, grain size, and additions on the yield point in compression, the yield deformation, and the modulus of plasticity of moulding sands. A new test is described in which the deformation with time of a sand under a selected load is determined, and the results obtained with this test are correlated with shrinkage in castings. It was found that moulding sands with a low movement under load give castings with no or reduced shrinkage.—B. C. W.

Clay, Fines, and Water Relationships for Green Strength in Moulding Sands. A. H. Zrimsek and R. W. Heine. (*Trans. Amer. Found. Soc.*, 1955, **63**, 575–581). Data on the effect of water content on the green compressive strength and tensile strength of clays and of clay–sand and clay–sand–silica flour mixtures are presented and discussed.—B. C. W.

The Influence of Moulding Materials on the Incidence of Hot Tearing. J. M. Middleton. (*Trans. Amer. Found. Soc.*, 1955, **63**, 99–108). Experiments described in a previous paper [*Ibid.*, 1953, **61**, 167–180] on the effects of ramming density, bonding agents, and pouring temperature on hot tearing in steel castings have been repeated under similar experimental conditions but with a larger casting. Casting size had little effect by clay-bonded test blocks, but with castings restrained by organically bonded sands the thermal conditions produced by the larger castings caused a more complete breakdown in the sand and thereby reduced both the incidence and extent of hot tearing.—B. C. W.

The Scabbing Defect. (*Trans. Amer. Found. Soc.*, 1955, **63**, 123–142). In this third progress report of A.F.S. Sand Division Committee 8–J, detailed results are given of the properties and scabbing tendency of 19 different sands. The results are also given of tests to compare the sensitivity of the scabbing test pattern used in previous work with that of three other test patterns. From measurements of the expansion and hot deformation characteristics of the moulding sands it is concluded that the unaccommodated expansion, i.e. the amount by which the expansion exceeds the hot deformation at any specific temperature, correlates closely with the scabbing tendency of the sands.—B. C. W.

Physical Properties of Steel Foundry Sands at Elevated Temperatures. H. W. Meyer. (*Trans. Amer. Found. Soc.*, 1955, **63**, 17–18). The history and accomplishments of the A.F.S. Committee 8–L are briefly reviewed.—B. C. W.

Modern Sand Quarry Developments at Redhill. (*Found. Trade J.*, 1955, **99**, Dec. 15, 705–707). The production and treatment of sands for the glassmaking and foundry industries at the quarries of British Industrial Sands Ltd. is outlined. The problems incurred in producing sands for the shell moulding and CO_2-processes are briefly referred to.—B. C. W.

Use of Zircon Sand in Producing Large Castings. H. Chappie. (*Foundry*, 1955, **83**, Oct., 126–131). The properties of zircon sand are reviewed and its applications in the foundry are considered. The use of a zircon sand facing reduces metal penetration and sand burn-on, and gives a smoother surface finish.—B. C. W.

Wood Pattern Construction Standards and Specifications. J. F. Roth. (*Trans. Amer. Found. Soc.*, 1955, **63**, 587–588). Specifications for different classes of wood patterns are proposed as a basis for subsequent discussion.—B. C. W.

Gypsum Cement Moulds for Plastic Patterns. M. K. Young. (*Trans. Amer. Found. Soc.*, 1955, **63**, 377–382). Several methods of making gypsum cement moulds for plastic pattern plates are illustrated and described.—B. C. W.

Pressure Moulding Influences on Pattern and Rigging. T. E. Barlow and W. J. Burke. (*Trans. Amer. Found. Soc.*, 1955, **63**, 191–194). The design of patterns and flasks for the high pressure and diaphragm moulding techniques is discussed in general terms.—B. C. W.

Current Status of Test Patterns for Evaluation of Sand Mixtures. C. Locke. (*Trans. Amer. Found. Soc.*, 1955, **63**, 49–62). The test patterns that have been and are being used in the foundry are illustrated and reviewed. Data are tabulated on 31 different test patterns. (46 references).—B. C. W.

Frozen-Mercury Patterns. I. D. Kramer. (*Aircraft Prod.*, 1955, **17**, Dec., 494–497). The advantage of low-volume changes in melting mercury makes possible the use of frozen mercury patterns for quite large and complex investment castings using shell-moulds. The process is described and some products are illustrated.—T. E. D.

Patterns Cast in Epoxy Resin. D. B. Orr. (*Found. Trade J.*, 1955, **99**, Nov. 10, 531–536). The preparation of master pattern replicas in a hardened and reinforced ethoxyline resin is described in detail. The process may be used for any split pattern but it is difficult to make double-side pattern plates as entrapped air in the resin gives slight pinholing on the upper surface.—B. C. W.

Modern Patternmaking Establishment. (*Found. Trade J.*, 1955, **99**, Dec. 8, 675–677). The development of the Universal Pattern Co. (London) Ltd. is outlined and the new works recently established at Crawley, Sussex, are briefly described.

The Construction and Setting of Patterns. H. Schiegner. (*Giessereitechn.*, 1955, **1**, Nov., 217–221). Difficulties and defects can be avoided by giving more time and attention

to the careful design of patterns and templates. A number of practical hints are given.—L. J. L.

Economics in Materials and Time in the Preparation of a Pattern. A. Lenke. (*Giessereitechn.*, 1955, **1**, Dec., 245–247). A practical example of pattern construction is given to prove that a high degree of stability and superior quality can be attained despite economies in materials and time.—L. J. L.

Expendable Pattern Materials for Investment Casting. C. D. Murphy, Jun. (*Precision Met. Mold.*, 1956, **14**, Jan., 52–54, 82–85, 89–90). The properties required of a modern pattern material are listed and discussed with special reference to wax compounds.—D. H.

A Simplified Method for Determining Riser Dimensions. H. F. Bishop, E. T. Myskowski, and W. S. Pellini. (*Trans. Amer. Found. Soc.*, 1955, **63**, 271–281). Experiments with steel castings showed that the surface area–volume ratio used to calculate riser dimensions can be replaced by the shape factor L + W/T where L is the length, W the width, and T the thickness of the casting. Graphs relating minimum riser volume to casting volume for different shape factors are given and the method used to calculate riser dimensions is illustrated by examples. Procedures and data are also given for determining the minimum riser dimensions required for complex shapes involving thin sections joined to heavier sections, and for shapes involving retarded cooling such as cylinders containing small cores.—B. C. W.

Risering of Commercial Steel Castings. C. W. Briggs. (*Trans. Amer. Found. Soc.*, 1955, **63**, 287–290). A method of rapidly estimating the minimum riser diameter for steel castings is given and a detailed calculation based on the method of Bishop, Myskowski, and Pellini (see previous abstract) is presented for a disc casting.—B. C. W.

A New Foundry Core Sand Binder. C. J. Gogek. (*Trans. Amer. Found. Soc.*, 1955, **63**, 472–472). The properties of cores prepared with a binder containing over 90% corn sugar are presented and briefly discussed.—B. C. W.

Reactions During Core Baking. G. J. Grott and H. F. Taylor. (*Trans. Amer. Found. Soc.*, 1955, **63**, 493–502). Previous work on the oxidation and polymerization of a drying oil is reviewed and discussed in relation to the baking of cores bonded with linseed oil. Some experimental results on moisture pick-up by cores at room temperature are reported and it is shown that oil sand bonds can be cured in a very short time if hot air is drawn through the cores.—B. C. W.

Mechanization of Mould Coating. I. P. Belyuchenko. (*Stal'*, 1955, (7), 660–661). [In Russian]. The use of a lacquer for mould-coating and the mechanization of the coating operation are described. Control of lacquer viscosity is considered.—S. K.

Behaviour of Steels During Solidification. W. Trommer. (*Giesserei*, 1955, **42**, Dec. 22, 708–715). The normal behaviour of steel during solidification is first described, using hydrostatic parallels. The after-suction of different riser shapes and the contraction on solidification are discussed. The controlled behaviour of steel after casting is considered briefly. The setting, isolating, and heating of risers are described and the principles of air- and gas-pressure risers elucidated. A description of the effect of tilting the mould after casting and the use of cooling media is followed by a discussion of casting under reduced or excess pressure, and of centrifugal casting.—R. J. W.

Your Can't Judge a Block by Its Appearance. R. E. Vandeventer and F. McFarland. (*S.A.E.J.*, 1955, **63**, Mar., 50–52). Residual stresses in cast cylinder blocks—due to unsuitable cooling rate—are often the cause of subsequent failure by cracking. A technique for measuring these stresses is described, in which readings are taken from electrical resistance strain gauges mounted on the block before and after making saw cuts in it (to relieve the stress). As a result of this test method, cooling cycles have been modified at the Packard factory.—P. M. C.

The Influence of the Mechanism of Formation of a Casting on the Structure of Cast Iron. V. M. Pischchev. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (8), 107–118). [In Russian]. Results of an investigation of the influence of the mechanism of formation of a casting and of casting technology on the size and distribution of graphite as well as on the microstructure of the main mass of the metal are described. The study of the microstructure was carried out on specimens cut from castings of ingot moulds centrifugically cast in moulds with dry cores. It is concluded that the microstructure of metal indicates the method of preparation of metal for casting while non-uniformity of the shape and size of graphite and of the microstructure of metal along the width and length of a casting, shows the mechanism by which the casting was formed. The above facts allow for the evaluation of the correctness of the chosen casting technique.—V. G.

REHEATING FURNACES AND SOAKING PITS

New System of Furnace Atmosphere Control. (*Brit. Engineering*, 1956, **38**, Jan., 263–264). The "Equiverse" system of the Incandescent Heat Co., Ltd., allows scale-free heating to 1300° C or above in direct-fired forge and reheating furnaces, by maintaining 12–16·5% of CO in the atmosphere. The CO is subsequently burnt in the rapidly reversing regenerative system. The furnaces show increased outputs per unit hearth area and lower fuel consumptions for a given weight of metal.—K. E. J.

Mains Frequency Induction Heating. R. H. Barfield. (*Wild Barfield Heat Treatment J.*, 1955, **5**, Dec., 10–15). The considerations affecting the use of high or mains frequency induction heating are explained. Some practical applications of the latter are given.—D. H.

King Size Furnace Handles Water Shipped Assemblies. H. F. Knab. (*Western Metals*, 1954, **12**, Aug., 52–53) Constructional and performance details are given of a very large car-hearth type furnace, installed by the Willamette Iron & Steel Co., Oregon, U.S.A. Inside dimensions are 20 ft. wide by 20 ft. high by 30 ft. long with lift doors at each end. The furnace will operate at up to 2100° F, is gas-fired, and is fitted with fully automatic temperature control.

Mechanized Continuous Furnaces. G. C. McCormick. (*Metal Progress*, 1955, **68**, Nov., 95–100). Existing machines are classified into 6 classes according to the method of handling the work. The advantages and disadvantages of each type are briefly stated and considerations which affect a decision to mechanize a heat treating department are given.—G. B. B.

Mechanized Batch-Type Furnaces. M. Neumeyer. (*Metal Progress*, 1955, **68**, Nov., 101–104). The advantages of batch-type furnaces for the annealing of steel parts are considered.—B. G. B.

The New Soaking Pits with Regenerators of the Dudelange Division (ARBED). J. Hein. (*Rev. Tech. Luxembourg.* 1956, **48**, Jan.–Mar., 11–24). A detailed description is presented of these new soaking pits, four in number, each with an ingot capacity of 50 tons. Blast furnace gas is used as fuel. The combustion air and gas are preheated in separate metallic recuperators; the gas to 400° C and the air to 600° C. Cold air is used to dilute the exit gases from the furnace to reduce the temperature to 800° C. Tests carried out on the furnaces to measure their efficiency are described and a heat balance is given. The track-time of the ingots is usually 1½ hrs, the soaking time 2 hrs and the furnace temperature 1290° C.—B. G. B.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

General Notes on Electrometallurgy. M. Fourment. (*Bull. Soc. Ing. Civils France*, 1956, No. 1, 17–34). Electrical methods of supplying heat for tempering are first considered. Electric melting techniques are next reviewed and resistance, arc and high frequency furnaces are described. Electrical methods of metal purification including vacuum fusion and zone melting are mentioned. The author concludes by surveying the present state and development of electric heating in metallurgy.—B. G. B.

Effect of Density Differences on the Path of Jets. G. Horn and M. W. Thring. (*Nature*, 1955, **175**, June 18, 1081–1082).

Improving Furnace Performance by Model Investigation. M. W. Thring. (*Coke Gas*, 1956, **18**, Mar., 101–103). In the application of model techniques to furnace design, a problem has been the simulation of the buoyancy effect of hot flames rising within the cooler furnace atmosphere. The technique, described and illustrated, involves the use of a jet of magnetite slurry, representing the flame jet, and water, representing combustion air. The dense jet of magnetite sinks, and so provides an "upside down" picture of the rising flame jet.—T. E. D.

The Planning of Tests for Solving Problems Related to

Materials and Their Heat Treatment. E. Rossow. (*Härterei-Tech. Mitt.*, 1955, **7**, (4), 29–51). The author discusses the planning of tests with a view to obtaining best results without unnecessary repetition. Statistical methods are included.

Gas as a Source of Protective Atmosphere in Industrial Furnaces. E. J. Funk. (*Indust. Heating*, 1955, **22**, Oct., 2030–2038). Principles of the production, use and control of exothermic and endothermic atmospheres for heat treatment are outlined.—A. D. H.

Optimum Heat Treatment for Magnetic Core Iron. H. A. Steinherz. (*Indust. Heating*, 1955, **22**, Oct., 1992–2000). A statistically designed experiment provided a rapid way of determining the correct heat treatment to obtain high values of permeability in 3¼% oriented silicon iron.—A. D. H.

Heat Treating Gray Iron. (*Steel*, 1955, **137**, Oct. 24, 118–122; Oct. 31, 76–79; Nov. 7, 134–136). The theory and practice of heat treating grey iron are described. Sections deal with stress relief and annealing, flame and induction hardening, and through hardening and hot quenching.

The Tempering of Plain Carbon Steels. E. D. Hyam and J. Nutting. (*J. Iron Steel Inst.*, 1956, **183**, 148–165). [This issue].

Heat Treatment Plant for Seamless Tubes. (*Engineer*, 1955, **200**, Oct. 28., 629–630). Details are given of a plant for the heat treatment of seamless steel tubes, installed in the works of Accles and Pollock by the Incandescent Heat Co. Ltd. The equipment comprises a continuous mesh belt-conveyor furnace with electric heating elements and a "Hi-Nitrogen" atmosphere generator.—M. D. J. B.

Molten Baths and Mechanisms. L. B. Rosseau. (*Metal Progress*, 1955, **68**, Nov., 106–110). The design of baths and handling mechanism for lead, oil, and salt are described.

Decarb, Distortion Exit with Salt Bath Furnace Treatment of Landing Gears. F. Fenger. (*Western Metals*, 1954, **12**, Sept., 47–49). The hardening procedure for very large aircraft components, at the Menasco Manufacturing Co., California, is described. Constructed mostly of SAE 4340 steel, the components are austenitized, quenched and tempered in "Aja" electric salt baths. Distortion is now practically negligible, and excellent strength and uniformity of hardness are achieved.—P. M. C.

Production Control of Salt Baths in Germany. O. Schaaber. (*Metal Progress*, 1956, **69**, Mar., 67–71). The carburizing potential of a salt bath is measured by immersing mild steel foil long enough to carburize throughout and estimating its carbon content. The quenching power of a martempering bath is measured by the time needed to heat a small cylinder through a specified range of temperature.—B. G. B.

Selection and Application of Furnace Atmospheres for Carbon Control. O. E. Cullen. (*Metal Progress*, 1956, **69**, Mar., 57–61). The use of a furnace atmosphere containing about 20% CO, 40% H_2 and 40% N_2 is described. It can be used to carburize, carbonitride, recarburize decarburized surfaces, clean harden or increase the carbon content of strip to a uniform higher level. Careful measurement and control of the dewpoint are needed.—B. G. B.

Sulphurizing or Sulphur Cementation. C. Ciffo. (*Ing. Mecc.*, 1955, **4**, Oct., 45–47). [In Italian]. The author describes a new heat treatment process which imparts a very high wearing resistance to materials without, however, altering their surface hardness. The method of preparing ferrous materials for sulphur cementation is described and the characteristics of the surfaces obtained and the means of testing the sulphurized layer are discussed.—M. D. J. B.

A Rapid Method for Determining the Properties of the Steel and the Carburizing Agent. A. Slattenschek. (*Härterei-Tech. Mitt.*, 1944, **3**, 99–121). A mathematical treatment of the problem is given. The equation of the carburization curve is applied to carburization processes. The diffusion constant of a steel is shown to be independent of the carbon content and it is given by the equation:

$$D = \frac{(Cm - C_K)^2}{F_1 s} \cdot \frac{d^2}{4Z}$$

—R. P.

The Problem of Depth of Chill and its Determination. J. Quadflieg. (*Härterei-Tech. Mitt.*, 1950, **6**, (1), 9–30). The results of co-operative work by several firms are discussed and standard conditions for testing the depth of case arrived at.—R. P.

Flame Hardening of Foundry Iron and Practical Application. H. W. Grönegress. (*Rev. Mét.*, 1955, **52**, July, 559–568). Carbon content and graphite distribution are the most important factors governing the flame hardenability of cast iron. At least 0·5% carbon is necessary for adequate surface hardness. Likewise the tendency to crack decreases the finer the graphite distribution. Examples of the use of flame hardened cast iron and of the special equipment for it are discussed.—G. E. D.

Surface Hardening by Induction Heat. H. B. Osborn. (*Metal Progress*, 1955, **68**, Dec., 105–109). The metallurgical aspects of this technique are discussed. The factors which determine the depth of the hardened layer and its properties are considered together with quenching techniques.—B. G. B.

Inductive Heat-Treatment. H. Jung. (*Härterei-Tech. Mitt.*, 1944, **3**, 177–187). Inductive heat-treatment apparatus is discussed in detail. The construction and mode of operation are described.—R. P.

Electrolytic Carburization. C. Albrecht. (*Härterei-Tech. Mitt.*, 1944, **3**, 91–98). A critical review of electrolytic carburization is made. Using salt baths and direct current, the carbon in the steel travels towards the cathode. The depth of hardening increases slightly with increase in current density. The cyanide content of the bath influences the rate of carburization. The method is not in practical use.—R. P.

The Possibility of Simultaneous Carburization and Oxidation of Steel During Case-Hardening. E. Scheil. (*Härterei-Tech. Mitt.*, 1955, **9**, (2), 27–29). Simultaneous carburization and oxidation is possible, provided the steel contains silicon. The equilibrium in question is discussed. No oxides are formed.

Oxidation at the Surface of Case-Hardening Steels. C. Albrecht. (*Härterei-Tech. Mitt.*, 1955, **9**, (2), 9–26). The carburization of case-hardening steels may be accompanied by oxide inclusions (particularly of silica) in the rim. They do not appear on the whole surface, only where slag seams are present, and they go to within 5 to 10% of the depth of carburization. These inclusions depend on the carburizing agent. High carburizing temperatures minimize surface oxidation.—R. P.

Two and a Half Years of Practical Experience in Gaseous Carburization of Driving-Gears Using Town Gas. J. Brugger. (*Härterei-Tech. Mitt.*, 1954, **9**, (1), 27–51). The construction and operation of furnaces for case-hardening are described. Details for obtaining gas of sufficiently constant composition are given, starting with town-gas. Gaseous carburization is considered more efficient and more economic than the use of powders. The heat-resisting material consists of an alloy containing 19% nickel and 24% chromium.—R. P.

Effect of Activators on Solid Case Hardening Compounds for Carburisation of Steel. H. Schrader. (*Arch. Eisenhüttenwesen*, 1955, **26**, Sept., 527–533). The author describes carburization experiments on steels containing (1) 0·14% C, (2) 0·19% C, 1·1% Mn, 1·0% Cr, and 0·2% Mo, (3) 0·15% C, 1·0% Cr, and 4·3% Ni. The additives used were oxides and carbonates of alkali and alkaline earth metals, and their effect on charcoal case-hardening compounds was investigated. It was found that the effect depended on their oxygen content, which went to the production of carbon monoxide (the effective carburizing gas), and also on the evolution of heat for the breaking down of oxides and carbonates to metals and carbon monoxide, and for the production of alkali and alkaline earth metal carbides to assist carburization.—A. C.

Versatile Steel Carburizing Process Provides Low Cost, Hard Surface Parts. J. B. Fromblom, and H. W. Hiemke. (*Western Metals*, 1954, **12**, Mar., 44–47). The history of the development of gas carburizing furnaces, up to the modern continuous self contained units is described. The chemistry of the various gases and mixtures used for carburizing and carbon restoration is outlined, and data are presented on various types of gas generators.—P. M. C.

Gas Carburizing. I. Commercial Practice. II. Application of Equilibrium Data. (*Metal Progress*, 1955, **68**, Aug. 15, 132–143). Batch and continuous furnaces and their maintenance are described. Details of commercial practice with undiluted hydrocarbon gases or liquids and with inert carrier gas in conjunction with hydrocarbon gases are given. The control of case depth and carbon concentration gradient is discussed. The practical application of equilibrium data is explained.—B. G. B.

Induction Hardening and Tempering. (*Metal Progress*, 1955, **68**, Aug. 15, 107–123). The selection and control of equipment and metals for commercial hardening and tempering by induction heating is discussed in detail. The results of some typical production application are presented.—B. G. B.

Work Coils for Induction Heating. D. W. Brown. (*Machinery*, 1955, **87**, Oct. 28, 1019–1026). The article deals with many aspects which have a bearing on the design of coils. It is stressed that it is very seldom that coils are evolved from theoretical considerations, and it is more usual in practice to make up an experimental coil based on a general understanding of the subject, and modify to suit conditions required.—M. A. K.

Advance Determination of the Depth of Chill Obtained by Induction Hardening. K. Kegel. (*Härterei-Tech. Mitt.*, 1955, **9**, (2), 31–44). It is considered difficult to clarify the heating and cooling processes during induction hardening by practical measurements. A mathematical treatment is worked out. A diagram shows how the depth of chill of steels with an Ac_3 point of 780–820° C can be predetermined when a frequency of 550 cycles/sec is used.—R. P.

Nitriding Improvements. G. Keller. (*Brown Boveri Rev.*, 1955, **42**, Mar., 88–93). A description of Brown Boveri nitriding plants and of results obtained are given.—B. G. B.

Control of Surface Carbon Content in the Heat Treatment of Steel. (*Metal Progress*, 1955, **68**, Aug. 15, 144–150). The application of carburizing–decarburizing potentials is explained and equipment for measurement and control of furnace atmospheres is described. Carbon restoration during annealing and hardening is reviewed. Atmospheres for heat treating tool and stainless steels, sintering of iron–carbon powder metal compacts, and brazing are considered.—B. G. B.

Water Annealing of High-Speed Steels. S. Owaku and H. Akasu. (*Tetsu to Hagane*, 1955, **41**, Nov., 1184–1188). [In Japanese]. Quenched high-speed steels can be rapidly and effectively water annealed, although the degree of softening is not so complete as with the longer complete annealing process. A schedule of 5–6 annealing operations with intermediate heat treatments is recommended. For parts of large dimensions or complicated shape, oil annealing is more effective.—K. E. J.

Batch-Type Strip Annealing Furnaces. C. F. Olmstead. (*Metal Progress*, 1955, **68**, Nov., 91–94). A short illustrated account of multiple and single stack cover furnaces for the annealing of steel strip is presented. The advantages of this type of furnace include, low fuel or power costs, shorter annealing cycles, and uniform product.—B. G. B.

An Aspect of the Heat-Treatment of Cast Irons: Softening by Annealing. G. Aubrion. (*Fonderie*, 1955, June, 4563–4572). The various softening treatments that may be applied to white and mottled cast irons are described and discussed. Details are given of softening heat-treatments applied to four different castings together with the changes in microstructure and hardness which were produced.—B. C. W.

A 450 kw Electric Bell-Type Furnace for Annealing Steel Rod. (*J. Four Elect.*, 1955, **64**, July-Aug., 135–137). An illustrated description of this furnace which can treat 20 tons of rod to a maximum temperature of 950° C is given. An inert atmosphere consisting of nitrogen with 2 to 5% hydrogen is used in the furnace. Examples of annealing and tempering curves obtainable are shown.—B. G. B.

Differential Annealing. A New Technique for Improving Deep Drawing. E. G. Maeder. (*Engineering*, 1956, 181, Jan. 13, 48–52). The author shows that a deep-drawing circular test piece in which the temper varies radially in a controlled manner can be cupped and redrawn to a substantially greater extent than a uniform circle and that the resulting product is more satisfactory. The effect of variations in temper across the blank is examined. A differential annealing machine is described which has enabled the theory to be confirmed by the production of shells with 60% cupping reductions.

Strengthening of Steels in Intermediate Stages. E. Rossow. (*Härterei-Tech. Mitt.*, 1944, **3**, 143–157). The properties of steels obtainable by various heat-treatment processes are discussed. The influence of section and alloying elements are considered.—R. P.

Comparison of Surface-Hardening Methods. P. Riebensahm. (*Härterei-Tech. Mitt.*, 1944, **3**, 63–79). Six methods of surface-hardening are compared and the results are shown diagrammatically.—R. P.

The Purpose and Results of Surface-Hardening. H. Müller. (*Härterei-Tech. Mitt.*, 1944, **3**, 81–90). This problem is discussed, using several examples of surface-hardened parts. Careful consideration and metallurgical knowledge are necessary in order to obtain good results.—R. P.

Flame Hardening. (*Metal Progress*, 1955, **68**, Aug. 15, 124–131). Methods of flame hardening, the gaseous fuels employed and the equipment used are first discussed. Data relating to the cost of flame hardening are presented for four applications (small gear, cam, ring gear, spur gear). Quenching procedures and tempering practice are described. The selection of material for flame hardening is reviewed.—B. G. B.

The Applications of 'Sulf-Inuz' to Aeronautics. P. Partiot. (*Métaux-Corrosion-Indust.*, 1955, **30**, Nov., 450–455). This technique involves the sulphurization of the surface layer of steel followed by heat treatment. The parts so treated have self-lubricating properties and surfaces in contact can be easily separated.—B. G. B.

The Surface Hardening of Steel Parts and Progress Made with Controlled Nitriding. R. Lambert. (*Rev. Mét.*, 1955, **52**, July, 553–558). Nitriding at constant temperature to produce an extremely hard surface has been carried out for a number of years. The development of controlled nitriding, at variable temperatures, to produce a more malleable nitrided surface and a more resilient core is discussed. The variations in the values of surface hardness according to the applied load is also mentioned.—G. E. D.

Nitriding Baths for Cutting Tools. H. Schaumann. (*Härterei-Tech. Mitt.*, 1944, **3**, 219–230). Treatment of tool steels in nitriding baths improves the surface finish and performance. The demands made on high-speed steels are discussed. A description of the process is followed by considerations of the influence of alloying elements. Various variables are investigated.—R. P.

Bath-Nitriding of Pressing Tools. H. Müller. (*Härterei-Tech. Mitt.*, 1944, **3**, 231–234). The method improves the performance and properties of pressing tools. The surface layer formed by nitriding is hard and often resists annealing.

New Knowledge Gained in Gaseous Carburization and Nitriding. T. Schmidt. (*Härterei-Tech. Mitt.*, 1954, **9**, (1), 9–26). The theory and applications of gaseous carburization and of three carbo-nitriding methods are discussed. The same furnaces can be used for all these processes. No special alloys are required for carbo-nitriding as compared with the nitriding process. Conditions for controlling the depth of chill are stated. (15 references).—R. P.

Air as a nitriding gas. R. Knox, Jun. (*Metal Progress*, 1955, **68**, Nov., 126). Tests show that mild steel can absorb nitrogen directly from the air when heated in the high temperature austenite region.—B. G. B.

Correct Bath Nitriding of High-speed Steel Tools. A. Rühenbeck and G. Schüssler. (*Metalloberfläche*, 1955, **9**, Nov., 196A–202A). Details are given of the correct procedures for bath nitriding high-speed steel tools. For deep nitriding a "broken nitriding" technique is described. The nitriding is carried out in stages, the material being held at a suitable temperature in a neutral bath between stages. A similar method is used for treating re-ground tools. The normal technique recommended consists in a preliminary heat treatment in neutral salts, followed by grinding and nitriding. It is indicated which groups of tools should be treated by this process. (22 ref.).—L. D. H.

Tool Steel Annealing. (*Metallurgia*, 1956, **53**, Jan., 34–36). A short description of three batch type annealing furnaces fired by town's gas and installed at Arthur Balfour and Co. Ltd. The furnaces are used for isothermal annealing of plain carbon, alloy, and high speed tool steels.—B. G. B.

How to Understand Annealing and Hot Working of Metals. S. Storchheim. (*Metalworking Production*, 1955, **99**, Dec. 23, 2169–2176). Metallurgical reasons for annealing a cold worked metal to relieve stresses are explained, together with methods of selecting whether hot or cold working should be adopted.—M. A. K.

Bainite Hardening of High-Speed Tool Steels. J. Hoch. (*Härterei-Tech. Mitt.*, 1951, **7**, (2), 35–46). Experimental details for Bainite hardening are given. The results of tests carried out in America and in Germany are quoted. The process is complicated and expensive.—R. P.

The Influence of Composition and Initial State on the Hardening of Structural Steels. A. Legat and A. Nöstelhaller. (*Härterei-Tech. Mitt.*, 1952, **8**, (1), 9–23). After discussing the aims of hardness testing, the authors consider the causes for variations in hardenability. The composition, grain boundary, and grain size of the steel influence its behaviour during the hardening process. It will not be possible to express hardness by a universally valid characteristic until an expres-

sion for the variation in homogeneity of austenite has been found. (11 references).—R. P.

Primary Hardening. Stabilizing. Annealing. W. Küntscher. (*Härterei-Tech. Mitt.*, 1944, **3**, 159–176). Hardening, stabilizing, and annealing treatments are discussed. The author recommends a combination of all three processes.

Principles of the Efficient Heat Treatment of Tools made from High-speed Steels. H. Springer. (*Härterei-Tech. Mitt.*, 1951, **7**, (1), 25–46). Efficient hardening is achieved by considering the properties of the high-speed steel in relation to available methods of heat-treatment. The results of hardness testing, temperature, etc., in various plants are discussed.—R. P.

Impressions and Observations in American Hardening Plants. W. Stuhlmann. (*Härterei-Tech. Mitt.*, 1951, **7**, (1), 9–24). The author compares American with German methods of hardening, carburization, nitriding, and heat treatment in general.—R. P.

Advantages and Disadvantages of "Bainite" Hardening of Low-Tungsten High-speed Tool Steels. F. W. Strassburg. (*Härterei-Tech., Mitt.*, 1955, **8**, (3), 9–23). The isothermal transformation diagrams of the steels in question are used as a basis for bainite hardening of high-speed steels. The transformation of austenite into bainite or martensite is accompanied by a small increase in volume, measured by a dilatometer. During bainite hardening, martensite formation is avoided, the volume change is smaller and internal tensions are minimized. Small residual amounts of austenite remain; special precautions are necessary. The method is recommended for complicated tools but not for small, plain ones.

The Hardening Temperature of Tool Steels and High Speed Steels. H. M. Hiller. (*Härterei-Tech. Mitt.*, 1952, **7**, (3), 9–27). The influence of temperature during hardening of various steels is discussed.—R. P.

What the Time–Temperature Transformation Curves Mean to an Engineer in Hardening Plants. W. Stuhlmann. (*Härterei-Tech. Mitt.*, 1954, **6**, (4), 31–48). The author shows how these curves are used, the properties which can be predicted from them and their limitations. The diagrams and graphs under discussion include those for iron-carbon, super-cooling, isothermal transformation and continuous cooling. (10 references).—R. P.

Internal Tension Produced During Hardening of Steel and its Significance in the Distortion and Formation of Cracks in Hardened Steels. E. Scheil. (*Härterei-Tech. Mitt.*, 1955, **7**, (4), 9–27). Measurements were made, using low-carbon iron-nickel alloys. Distortions were studied by means of a spar model. Thermal strain causes internal cracking whereas tensions during transformation produce cracks on the surface. Micro and macro cracks appear some time after hardening. These defects can be partly avoided by gentle annealing immediately after hardening. (12 references).—R. P.

Calculations in Hardening Plants. H. Müller. (*Härterei-Tech. Mitt.*, 1953, **6**, (3), 29–38). Underlying principles for calculations are discussed and examples from several firms quoted.—R. P.

Problems in Hardening Large Numbers of Small Parts, with Particular Reference to Screws. A. Hancke. (*Härterei-Tech. Mitt.*, 1953, **6**, (3), 9–27). A survey of the technical developments for producing hardened screws. Several methods are compared and installations described.—R. P.

Modern Isothermal Heat Treating Methods Reduce Warpage, Cracking. B. P. Planner. (*Western Metals*, 1954, **12**, July, 43–47). The basic transformations occurring in conventional quenching and tempering are discussed with reference to isothermal transformation diagrams and end-quench hardenability curves. The several advantages of isothermal transformation when applied to production heat treatment are reviewed.—P. M. C.

Method of Determining the Depth of Cementation of Alloy Steel by Means of Isothermal Hardening. M. M. Zamyatnin, Yu. V. El'tsin and B. I. Zvyagin. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 687–692). [In Russian]. By soaking the specimen at a constant temperature the boundary of the carburised layer at a carbon content depending on the temperature is made very distinct. The method is suitable for works-laboratory conditions, but is not applicable to some low-alloy and carbon steels. Errors due to variations in chemical composition within the specified range can be allowed for by fixing the bath-temperature according to the effect on the position of the martensite point.—S. K.

New Advancements in Hot Salt Quenching. Q. D. Mehrkam. (*Indust. Heating*, 1955, **22**, Oct., 1980–1990, 2210–2213). Methods of austempering and martempering are discussed and the addition of 1–2% water to nitrate-nitrite salt baths to improve quenching power and an improved design of salt bath for salt quenching are described.

Austempering Gives 50% Stronger Chain Saw Parts at McCulloch Motors. L. B. Reed. (*Western Metals*, 1955, **13**, May, 70). Chain saw parts, in 0·80% carbon steel, are now salt quenched for 20 minutes at 500° F, as compared with the conventional quench to below 100° F followed by tempering. This change in procedure has resulted in parts with greater toughness and ductility.—P. M. C.

FORGING, STAMPING, DRAWING, AND PRESSING

Massive Forgings Made Possible by Installation of Schloemann Press. (*B.H.P. Rev.*, 1955, **33**, Dec., 14–16). A description is given of the construction, installation and operation of the Schloemann hydraulic forge press recently installed at the Waratah works of Commonwealth Steel Co., Australia. The press can handle ingots up to 150 tons, and is producing heavy forgings for gear rings and shafts.

On the Plastic Shaping of Metals. K. W. Michler. (*Metall*, 1955, **9**, Dec., 1089–1092). Formulae and nomographs for the determination of blank dimensions for axially symmetrical pressings are quoted, and guidance is given on the choice of presses and calculation of loads.—J. G. W.

Development of Steel Forging Process in Japan. S. Kobayashi. (*Tetsu to Hagane*, 1955, **41**, July, 762–770). [In Japanese]. Although production in 1953 was only 38% of the 1940 figure, modern techinques have been introduced in recent years, including heat, metallurgical and quality control systems and ultrasonic inspection. Production methods for heavy shafts etc. are described.—K. E. J.

Investigation of a Friction-Lift Drop Hammer. P. Grüner and E. Kraft. (*Arch. Eisenhüttenwesen*, 1955, **26**, Sept., 507–518). Developments in the construction of hammers in Germany and elsewhere are discussed. The authors examine the problem of shock on foundations, and discuss the results of research on various types of hammer. They describe their own tests, which were carried out with three different weights of tup under various working conditions, and analyse their results.—A. C.

The Design of Closed-Die Forgings. (*Metal Progress*, 1955, **68**, Aug. 15, 65–75). A comprehensive discussion of this subject is presented. Forging tolerances and allowances for subsequent machining and cleaning are considered. Hammer forging is primarily reviewed but data relating to hot upset forging and hot extrusion forging are included in the discussion.

Bending and Allied Forming Operations. T. G. Perry. (*J. Inst. Metals*, 1955-56, **84**, Mar., 211-216). The metallurgical factors involved in plain bending, tube bending, flanging, and rolling are discussed. The concept of the strain hardening exponent is used to provide empirical relationships for rolling-machine capacities and for buckling criteria in bending.—B. G. B.

Ductility of Unalloyed and Lightly Alloyed Steel During Hot Upsetting. K. Fink, W. Lueg and G. Bürger. (*Arch. Eisenhüttenwesen*, 1955, **26**, Nov., 655–668). The literature of the subject is reviewed, and a method is described for the determination of ductility-strain curves in hot upsetting under a hammer. Investigations on normalized cylindrical test-pieces are reported, and results are given. The effects of carbon content and hot working in the α and γ states are discussed, and the dependence of ductility and re-crystallized grain size on the original grain size is indicated.—A. C.

The Forging and Heat Treating of Tool Steel. (*Metal Progress*, 1955, **68**, Aug. 15, 151–157). The general procedures for forging and heat treating tool steels are outlined. Information on the heat treatment of over 90 specific American tool steels is presented in tabular form.—B. G. B.

Recent Accidents with Large Forgings. E. E. Thum. (*Metal Progress*, 1956, **69**, Feb., 49–57). The case history of the failure in service of 4 large forged rotors is presented. Two failures were due to unduly high stress concentrations introduced by the design or by a repair. The other two failures were due to misinterpreting or minimizing the evidence of internal defects found by ultrasonic inspection. Methods of preventing such failures are discussed.—B. G. B.

Continuous Line Stamps, Welds Housings Faster. H. Chase.

(*Iron Age*, 1956, **177**, Feb. 23, 90–93). The production scheme introduced when General Motors Co. (Buick) adopted a new design for rear axle housings is described. The integrated stamping and welding line handles 0·18 in. thick steel from coils and automatically produces 120 housings per hour.

Theoretical Considerations in Tube Drawing. F.-W. Neumann and D. Hancke. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1452–1460). An equation is developed using the fundamental assumptions of plastic forming. This is used in conjunction with equilibrium considerations to calculate groove dimensions for reducing rolls with both adjustable and fixed speeds. Mathematical determination of the length of the thickened tube ends is also attempted. Theoretical and practical results are compared.—A. C.

Research on Drawing of Steel Tubes. T. Okamoto. (*Tetsu to Hagane*, 1955, **41**, Dec., 1252–1258). [In Japanese]. Drawing and plug stresses are examined for the cases of drawing to a smaller wall thickness with constant internal diameter, and of reducing both wall thickness and diameter. From observed results, additional terms are introduced into the equations describing the process. (20 references).

West's Largest Steel Tube Drawbench at Pacific Tube Has 150,000-lb Pull. (*Western Metals*, 1954, **12**, Mar., 48–49). A brief description with illustrations is given of a new tube drawing plant by Aetna-Standard, installed at Pacific Tube Co., Los Angeles. Steel tubing with an O.D. up to 6½ in. can be drawn in lengths up to 52 ft. A drawing speed of 160 ft. per min. can be attained on carbon steel tubes of 3¼ in. O.D. by ⅜ in. wall thickness.—P. M. C.

Reel Drive Selection. R. K. Larson. (*Wire and Wire Prod.*, 1955, **30**, Oct., 1167–1177, 1291–1292; Nov., 1359–1367). The main types of reel drives and their control are defined and examples of design described, with particular application to take-up and pay-off reels in wire production. There follows a listing of characteristic performances of the various types of drives, of typical requirements, and guidance on the selection of the most suitable types for different applications. Finally, special design problems, e.g. of acceleration and deceleration, are discussed in detail.

Factors affecting the Characteristics of $Ca(OH)_2$ in Suspension, with Special Reference to the Wire-drawing Industry. T. C. Miller. (*Wire and Wire Prod.*, 1955, **30**, Oct., 1212–1218, 1297). Data are presented on the changes in the physical structure of $Ca(OH)_2$ under mill conditions. Freshly slaked lime is a more suitable lubricant carrier than hydrated lime; formation of coarse crystals is to be avoided. Experiments are quoted from which it is evident that crystal growth occurs on coils of wire or other submerged bodies with temperatures in excess of 103° C. By admitting live steam to the bath this formation of crystals can be avoided.—J. G. W.

Extruding Metal with Glass Lubricants. J. Delcroix. (*Metal Progress*, 1956, **69**, Jan., 57–60). A description of the use of glass as a lubricant between the hot billet and the chamber and die in an extrusion press in the Ugine-Séjournet process is given.—B. G. B.

Troubles with Cold Extrusion May be Traced to Lubrication. J. F. Leland and J. W. Helms. (*S.A.E.J.*, 1954, **62**, Nov., 43–45). The application of phosphate coatings to facilitate subsequent cold extrusion of metals, including steel, is discussed. Brief details are given of a suitable coating and lubricating cycle comprising alkali cleaning, water rinse, acid pickle, cold water rinse, hot water rinse, phosphating in Bonderite bath, water rinse, neutralizing rinse in Parcolene 20, and finally, application of lubricant in Bonderlube 235 reactive lubricant bath.—P. M. C.

Determine the Interference Fit and Resulting Stresses in the Design of a Cold Extrusion Die. C. R. Bradlee. (*Gen. Motors Eng. J.*, 1955, **2**, July–Aug., 38–39). Problems involved in the design of cold extrusion dies are discussed briefly and a problem is put forward for solution which involves the calculation of the stresses in a die treated as a heavy-walled cylinder. A number of fixed conditions are laid down, and the solution of this problem is given in the Sept.–Oct. issue of this journal.—E. A. C.

ROLLING-MILL PRACTICE

Investigation of the Influence of Different Factors on Roll Pressure, Energy Consumption, Spread and Forward Slip in Hot-Rolling. G. Wallquist. (*Jernkontorets Ann.*, 1955, **139**, (12), 923–1030). [In English]. An account is given of the influence of steel composition, temperature, reduction and material thickness on roll pressure, energy consumption, spread and forward slip. Sixteen steels were studied in an experimental mill, the temperature range being 800–1100° C. The pass reductions were 10, 20, 30 and 40%, and the material widths 2·5, 5, 10 and 20 mm.—G. G. K.

Moh i Rana: Norway's Promise of Self-Sufficiency. (*Brit. Steelmaker*, 1956, **22**, Jan., 20–22, 24). Details and illustrations are given of the three main rolling mill units supplied by Davy & United Engineering Co. Ltd. to the new Moh i Rana plant in Norway. The units are a 48 in. × 108 in. high-lift reversing blooming and slabbing mill, a 32 in. two-high reversing three-stand structural mill, and a complete 19-stand Morgan combination merchant bar, wire rod, and strip mill.–G. F.

Cold Rolling Properties of Transformer Steels Containing More than 3·3% Si. F. Lihl and P. Zemsch. (*Arch. Eisenhüttenwesen*, 1955, **26**, Oct., 599–602). The limits of deformation of a steel containing 4·3% Si and 0·25% Al are indicated. Experiments in the rolling of pre-heated alloys are described. The conditions for the malleability of high-silicon transformer steels, and the influence of rolling speed and cleanliness on grain size and orientation, are among other matters discussed.

Impressions of a Visit to American Rolling Mills (excluding Strip and Sheet Mills). P. Foulle. (*Centre Doc. Sidér., Circ. Inform Tech.*, 1956, **13**, (1), 169–176). Blooming mills and section, bar, and rod mills are described. It is particularly noted that there is less reheating and quicker roll changing than in Europe.—T. E. D.

One Failure of Tafel's Method. G. K. Gedevanishvili. (*Stal'*, 1955, (7), 651). [In Russian]. A recently suggested failure of the Tafel method of calculating extension during rolling is briefly examined and disproved.—S. K.

Rational Design of Finishing Round Passes. V. A. Khorosh. (*Stal'*, 1955, (4), 342–346). [In Russian]. Various methods at present used for the design of round passes for finishing round sections are critically reviewed and a rational procedure for pass design is proposed. including factors influencing the constancy of adjustment. The analysis leads to four rules for pass design and a worked example is given.—S. K.

Design of Round Passes for High Quality Steel. S. G. Nekrasov. (*Stal'*, 1955, (4), 339–342). [In Russian]. The finishing hot rolling of round sections to close tolerances and to obtain high-quality surfaces is discussed. These requirements can be met without changing rolls for a wide range of steels by using a finishing psss slightly widened along the horizontal axis. The theory of the operation of such rolls is considered. The use of this design is said to increase roll life and productivity and to decrease rejects.—S. K.

The 11 in. Rod Mill at Jones and Laughlin's Aliquippa Plant. N. A. Hansen. (*Iron Steel Eng.*, 1955, **32**, Aug., 90–93). Details are given of a new 11 in. rod mill consisting of 8 stands in the roughing train, 8 stands in the intermediate train and 6 stands in the finishing train. The unit is designed for speeds up to 6400 f.p.m. Roll outputs of 1180 tons per day, 491 tons per shift and 24,500 tons per month have been achieved. Rod sizes range from 0·218 in. to $\frac{31}{32}$ in.—M. D. J. B.

Investigation of the Working Conditions of a Medium-Sheet Mill. N. A. Chelyshev. (*Stal'*, 1955, (5), 440–444). [In Russian]. Experiments carried out on a medium sheet mill with two three-high stands are reported. From the observations of power consumption and the reductions achieved in the various processes an improved system has been devised.

Progress in Rolling of Flat Steel in Japan. S. Uchikawa. (*Tetsu to Hagane*, 1955, **41**, July, 744–756). [In Japanese]. An account is given of improvements and new plant installed since 1946 for producing sheet, plates, galvanized sheet, normal and electrolytic tinplate, etc.—K. E. J.

New Strip Mill Opened at Port Kembla. (*Chem. Eng. Min. Rev.*, 1955, **48**, Nov., 37–41). An illustrated account is given of this new mill which has a capacity of 1,500,000 tons of coiled strip a year.—B. G. B.

The Instrumentation of a 14-inch Experimental Rolling Mill. S. S. Carlisle and G. W. Alderton. (*Proc. Inst. Elect. Eng.*, Preprint M 1933, 1955, Nov.). The instrumentation scheme applied to the new 14-in. experimental mill at the Sheffield laboratories of B.I.S.R.A. is described in detail. Roll force, front and back tensions and strip gauge are continuously indicated on servo-operated potentiometric indicators, using the B.I.S.R.A. gaugemeter principle. Experimental work has been done on automatic gauge control, and it has been shown to be possible to operate a system of on/off

control of the existing a.c. screw motors. Possibilities of continuous gauge control, with simultaneous gauge-error indications are discussed.—L. D. H.

The Effect of Adding Molybdenum on the Life of Chilled Cast Iron Rolls used for Hot-Rolling Thin Steel Strip. M. Honzík. (*Hutnické Listy*, 1955, **10**, (12), 720–725). [In Czech]. Additions of molybdenum in excess of 0·3% were found beneficial, as they reduced wear and internal stresses of the chilled, hard, surface.—P. F.

New Combined Multi-Roll Mill for Rolling Thin Strip. A. I. Tselikov, A. A. Korolev and N. P. Zhetvin. (*Stal'*, 1955, (3), 238–243). [In Russian]. Roll-arrangements for the rolling of thin (0·1–0·2 mm) and very thin (0·01–0·05 mm) strip from carbon and alloy steels are discussed, the disadvantages of those used at present in the U.S.S.R. being considered. A new multi-roll mill is described, in which one of the working rolls is considerably larger than the other. The construction and operation of a prototype are outlined, some results being given. These show that great increases in productivity can be expected from the use of the new type of mill.—S. K.

Sheet Steel Manufacture: Capacity Rating of Modern Continuous Strip Mills. J. H. Mort. *Iron Steel*, 1955, **28**, Nov. 30, 548–554). The author indicates the necessity for a yardstick by which the capacities of hot and cold mills may be measured. He submits methods and formulae which enable the capacity rating of any mill to be equated with capital outlay and production costs, and which facilitate comparisons to be made between its performance and that of other mills, irrespective of size. Examples of the procedure in applying the formulae are presented.—G. F.

Electrical Equipment of a Four-Stand Strip Mill in Monmouthshire. P. C. Dannatt. (*Engineer*, 1955, **200**, Sept. 30, 474–475). This article describes the 4-stand tandem cold strip mill at the Newport Works of the Whitehead Iron and Steel Co. Ltd. The mill is designed to operate at speeds up to 2000 ft. per minute and to roll 14 in. wide strip down to 0·03 in.—M. D. J. B.

A Study of Cold Rolling. M. Massin. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sc3, 1–12). An account is given of the principles, equipment and procedure of a method of thermal analysis for studying the latent energy of cold rolling. This laboratory method is essentially a form of differential thermal analysis and its application is demonstrated by a number of examples.—E. C.

Rolling Repeated Shapes. S. N. Filipov. (*Stal'*, 1955, (8), 727–729). [In Russian]. The use of rolling methods as aid or substitute for the stamping of shapes is discussed. The effects of operating factors on the constancy of dimensions of the product are dealt with, and operating methods are briefly considered.—S. K.

Electrical Control for the Processing of Transformer Core Steel. E. F. Boening and J. Kostelac. (*Blast Furn. Steel Plant*, 1956, **44**, Feb., 199–206). A description is given of the control equipment for the rolling of grain orientated silicon steel sheet at the Midland Works of Crucible Steel Co., U.S.A.—B. G. B.

Automatic Gauge Control Applied to Cold Reduction Mill. W. E. Miller. (*Blast. Furn. Steel Plant*, 1956, **44**, Jan., 61–63). A short account of an X-ray type automatic gauge control fitted to a 5-stand tandem strip mill at the Irvin Works of United States Steel Corporation is given.—B. G. B.

Production of Cold Rolled Transformer Steel. N. I. Sheftel'. (*Stal'*, 1955, (7), 635–637). [In Russian]. The properties required of transformer steel are discussed in relation to its production, with special reference to the cold-rolling process. In cold-rolling the controlling factor together with heat treatment was found to be the total reduction in the final rolling to the required dimensions. Present production methods are discussed and suggested lines of research, including the production of metal with lower sulphur, oxygen, and nitrogen contents, decarburization and continuous heat treatment, are enumerated.—S. K.

On the Rational Technology for the Production of Cold-Rolled Auto Sheet. G. D. Rogoza. (*Stal'*, 1955, (7), 616–621). [In Russian]. The production of steel for the car industry and its hot and cold rolling are discussed. Optimum conditions are listed.—S. K.

West's First Sendzimir Reversing Mill Cold Rolls Super-Thin Strip. J. E. Lewis. (*Western Metals*, 1955, **13**, Sept., 51–53). The first cluster type Sendzimir mill in the Western U.S.A. has been installed at Calstrip Steel Corp., Los Angeles. The mill will roll ferrous and non-ferrous strip down to 0·005 and 0·003 in. gauge and 13 in. widths. Tolerances can be held to ± 0·001 in. Incoming stock is 0·125 in. thick in coils weighing up to 3400 lbs. The main features of the mill and its associated roll grinding facilities are described.

Roll-Forming. H. Pelphry. (*Aircraft Prod.*, 1955, **17**, Nov., 466–470). The Roto-Flo process for cold rolling of teeth and splines is described and illustrated. The advantages are discussed.—T. E. D.

Manufacture of Cold Formed Structural Sections. (*Engineer*, 1955, **200**, Aug. 19, 263–264). Details are given of the method of manufacturing cold-formed portal frames, as carried out by Metal Sections Ltd.—M. D. J. B.

The Modern Pilger Mill. J. M. MacKinnon. (*Anvil*, 1955, **3**, Summer Issue, 4–7). A description is given of a new pilger mill installed at the Calder Works of Stewarts & Lloyds Ltd. It is designed to produce tubes up to 10¾ in. dia. and 80 ft. long.

Experimental Determination of Stresses in a Type KhPT-75 Cold-Rolling Tube Mill. V. I. Sokolovskiĭ and V. S. Gashukov. (*Stal'*, 1955, (3), 247–251). [In Russian]. An account is given of an investigation of stresses in the critical parts of a moving-stand mill when rolling tubes of various steels under a variety of conditions. The transducers used were designed to give correct indication of stress even when their loading was somewhat eccentric. The pressure on the rolls during forward movement of the stand was found to be practically independent of the frequency of movement (in the range of 60–70 per minute) and the nature of changes during movement was very similar in either direction. From these and other results suggestions for improved working are deduced.

Electrical Drive Systems for Modern Rolling Mills. E. H. Browning. (*Blast Furn. Steel Plant*, 1956, **44**, Mar., 299–308). A review of modern electric drives is presented and comparison with earlier types is made.—B. G. B.

Magnetic Amplifiers for Rapid Control of Rolling Mill Drives. (*Stahl u. Eisen*, 1955, **75**, Dec. 1, 1645–1646). Letters to the Editor from Gustav Lemcke and Max Syrbe on the paper by Joachim Wetzger in "Stahl u. Eisen," pp. 478–85, are reproduced, and Herr Wetzger replies to the points raised.—A. C.

Electrical Equipment of Temper Mills. S. A. G. Emms and G. F. J. Morgan. (*Elect. Rev.*, 1955, **157**, Dec. 30, 1245–1251). The electrical drives and controls of single and two-stand sheet temper mills are described in detail.—L. D. H.

Problems of Control in Modern Rolling Mills. H. Mathiot. (*Centenary Congress of the Société de l'Industrie Minérale*, June 1955, Sel, 1–14). The application of servo-mechanisms in mill operation and motor control is discussed. Various types of servo-mechanisms are described and examples of their use are given.—E. C.

Photothyratron Indicator of the Position of Work Being Rolled. S. V. Svechnikov. (*Stal'*, 1955, (7), 658–660). [In Russian]. The design and uses of a robust device developed for automation purposes in rolling mills are described. The device is based on a combination of photo-cell and thyratron and indicates the position of the material being rolled.—S. K.

New Plate-Working Machines. (*Brit. Eng.*, 1956, **38**, Feb., 284–286). Details are given of new five-roll plate-levelling, and plate bending and straightening machines, made by Joshua Bigwood & Son, Ltd. The former has two alternative sets of rolls, for heavy, narrow plates and light, wide plates, respectively.—K. E. J.

Slitting Highly-Finished Stainless Steel—Precision Cutting Followed by Inspection. (*Engineering*, 1955, **180**, Oct. 14, 542–544). This article describes a precision pull-through slitting machine specially designed to ensure that there is no damage done to the highly-finished surface of stainless steel strip. The machine was designed and built by W. H. A. Robertson & Co. Ltd. for the Shepcote Lane works of Firth Vickers Stainless Steels Ltd.—M. D. J. B.

High-Speed Straightening of Steel Tubes. Large Diameter Range and Automatic Operation. (*Engineering*, 1955, **180**, Oct. 28, 606–607). The article describes a machine, claimed to be the largest in the country, for straightening tubes. It will be used in the production of high-grade, hot-finished steel tubes for oil pipelines, and is designed to operate over a diameter range of 3 in. to 15 in.—M. D. J. B.

Use of Manipulators on the Back Side of a Blooming Mill. B. M. Shum. (*Stal'*, 1955, (3), 243–246). [In Russian]. Data are presented showing the advantages of manipulation on the back as well as the front side of a blooming mill.

The application of manipulation for various operations is considered and the design of manipulators is touched on.

Performance Factors Affecting Bar Mill Cooling Bed Arrangement. E. C. Peterson. (*Iron Steel Eng.*, 1955, **32**, July, 65–74). This paper discusses cooling bed capacity and particularly the ability of the bed to discharge bars from the mill run out table, the ability of the bed to cool the mill production and the ability of the cold bar shear to dispose of the cooled bars.—M. D. J. B.

Electric Overhead Travelling Cranes. S. Maia. *Costruzioni Met.*, 1955, **7**, Mar–Apr., 17–25). [In Italian]. This paper describes developments in the structural design, mechanics and electrics of E.O.T. cranes in the U.S.A. Reference is made to specifications, working conditions and maintenance requirements. The author's conclusions are that, generally speaking, equipment is considerably heavier and more robustly designed in the U.S.A. than in Europe. (8 references).—M. D. J. B.

Steelworks Electric Overhead Travelling Cranes. (*Engineer*, 1955, **200**, Oct. 21, 591–592; Oct. 28, 615–616). A detailed account is given of a conference on steelworks cranes arranged by the British Iron & Steel Research Association at Harrogate on Oct. 5 and 6. Abstracts of the papers read are given, together with brief reports of the discussions.

Kilovar, Kilowatt and Voltage Control in the Steel Industry. L. G. Levoy. (*Iron Steel Eng.*, 1955, **32**, July 81–87). This article covers the fundamental considerations of kilovar, kilowatt and voltage control, without going into circuit details. (5 references).—M. D. J. B.

Cooling Towers for Steel Plants—Why, When, Where and How.—H. E. Degler. *Iron Steel Eng.*, 1955, **32**, July, 105–112). This article describes water requirements for steelworks, water supplies, methods of conserving water, cooling systems, mechanical and natural draught towers, and methods of operating and maintaining equipment.—M. D. J. B.

Synchronous Condensers for Steel Mill Service. E. I. Pollard. (*Iron Steel Eng.*, 1955, **32**, July, 129–134). The author shows that the synchronous condenser, either alone or in combination with a buffer reactor or a series capacitor or both, can provide an effective method of keeping voltage flicker due to reactive load swings of an electric arc furnace within acceptable limits. (7 references).—M. D. J. B.

Cold Roll Forming. E. J. Vanderploeg. (*Iron Steel Eng.*, 1955, **32**, Oct., 76–80). The author describes a process of forming metal from sheet, strips or coiled stock, into shapes of uniform cross-section, by feeding the stock longitudinally through successive pairs of rolls, each pair of rolls progressively forming the stock until the finished cross section is produced.

Design and Construction of Transformers for the Steel Industry. W. W. Renburg. (*Iron Steel Eng.*, 1955, **32**, Oct., 66–75).—This paper presents some of the most important problems encountered by the transformer designer and discusses the most effective methods of solving these. (6 references).—M. D. J. B.

Function of the Engineering Department in a Steel Plant. F. C. Schoen. (*Iron Steel Eng.*, 1955, **32**, Oct., 59–63). The author discusses the best means of organizing and administrating an engineering department in a small to medium sized steel plant employing from 1000 to 5000 men.—M. D. J. B.

Protective Devices on Ore and Coal Bridges. S. Tatalovich. (*Iron Steel Eng.*, 1955, **32**, Oct. 97–103). Protective devices on long travel, trolley, apron hoist, bucket hoist and hopper mechanism are described in some detail.—M. D. J. B.

Selection of Spares for a Steel Plant. R. Boyer. (*Iron Steel Eng.*, 1955, **32**, Sept., 111–112). The author discusses the problems that arise when the initial spares are being purchased to maintain new steel plant equipment. The solution is to carry the minimum amount of spares compatible with safe working.—M. D. J. B.

Overhead Crane Maintenance. G. T. Raubach. (*Iron Steel Eng.*, 1955, **32**, Sept., 99–102). The author discusses the essential steps to be taken to ensure good crane maintenance. The importance of gantry alignment, reliable power supply, inspection, lubrication and adjustment of mechanical and electrical components are stressed.—M. D. J. B.

Power and Control Cables for Steel Mills. E. D. Youmans. (*Iron Steel Eng.*, 1955, **32**, Sept., 81–87). A review is made of various types of power cable suitable for voltages over 5000, from 2000 to 5000 and below 2000.—M. D. J. B.

A New Concept in D-C Motor Design. R. A. Geuder and W. R. Hough. (*Iron Steel Eng.*, 1955, **32**, Aug., 82–84). The authors make a quick review of recent developments in D.C. motor design, for use in steelworks. The better acceleration and available torque characteristics of motors with dynamic response are discussed.—M. D. J. B.

Hot Scarfing with a Mechanical Bloom Turner. A. B. Glossbrenner. (*Iron Steel Eng.*, 1955, **32**, Aug., 77–80). The author describes a new hot scarfing machine recently installed at the Timken Roller Bearing Co. which has resulted in a 100% increase in production requiring only 50% of the previous manpower.—M. D. J. B.

An Analysis of Wheel Suspensions on Ore Bridge Main Trolleys. B. M. Osojnak. (*Iron Steel Eng.*, 1955, **32**, Aug., 70–76). This article describes a spring suspension system for ore bridge trolleys similar to that adopted in railway practice for handling high axle loads. The system is claimed to reduce maintenance and lubrication.—M. D. J. B.

Hydraulic Systems on Charging Machines and Manipulators. R. S. Bogar. (*Iron Steel Eng.*, 1955, **32**, Aug., 57–68). This paper describes the hydraulic open-hearth charging machines in two plants. The problems experienced are representative of most of the problems common to hydraulic machines. Brief consideration is also given to 3 axle plant manipulators, one axle plant charger and one plate mill charger.—M. D. J. B.

Non-Flammable Fluids as Applied to the Steel Industry. C. R. Schmitt. (*Iron Steel Eng.*, 1955, **32**, Sept., 128–132). The author discusses the merits of non-inflammable fluids which are chemically different from petroleum hydraulic fluids. Applications in the iron and steel industry are listed.—M. D. J. B.

Problems in Operating and Maintaining Steel Plant Equipment. J. F. Oehler. (*Iron Steel Eng.*, 1955, **32**, Sept., 119–122). This paper discusses some of the general and specific problems that arise in the operation and maintenance of steel plant equipment. Stress is placed on the need for close co-operation between the production and maintenance departments.—M. D. J. B.

Instruments for Rolling Mills and Steel Works. P. R. A. Briggs. (*Anvil*, 1955, **3**, Christmas Issue, 8–10). A very brief description of meters designed for testing loads on rolling mills and cranes is given.—B. G. B.

Smog Control Near 100% for Steel Mills and Foundries. M. A. Brower. (*Western Metals*, 1954, **12**, Jan., 48–50). The problem of air pollution in Los Angeles County is discussed, and the great progress made since 1953 is reviewed. The use of electrostatic precipitators and bag houses has reduced pollution emissions by about 95%.—P. M. C.

MACHINERY FOR IRON AND STEEL PLANT

Maximum Permissible Stresses in Crane Structures. Certain European Specifications. W. Lo Varco. (*Acciaio Costruzioni Met.*, 1955, **7**, Sept.-Oct., 29–37). [In Italian]. The author compares the permissible stresses tested in French, German, Italian, and British specifications for crane structures designed in ordinary and high tensile steels.

Intercommunication in the Iron and Steel Industry. J. D. Damper. (*Iron Coal Trades Rev.*, 1955, **171**, Dec. 23, 1525–1531; Dec. 30, 1583–1590). A survey is given of the various means of intercommunication at the disposal of steelworks operatives. Descriptions are given of electronic systems, line communications, carrier current systems, telesonic and radio units, television, loudspeakers, telemeters, and pneumatic tube systems. Applications of many units are illustrated, and factors to be considered when selecting a suitable system are discussed.—G. F.

There Are Indirect Benefits from a Furnace Fume Collector. E. F. Anderson. (*Foundry*, 1955, **83**, Sept., 152–153). A brief description is given of a fume collector fitted to a small electric arc furnace and the incidental advantages arising from its installation are briefly summarized.—B. C. W.

Continuous Thickness-Tolerance Measurement in Industry. N. A. S. J. Kootstra. (*Process Control Automation*, 1955, **2**, Aug., 303–306). An electronic instrument is described by the use of which deviations in thickness of thin sheet or wire can be measured during manufacture without disturbing production. The material is led between two rollers, the upper one being movable and spring-loaded, and connected to an inductive displacement pick-up. The instrument is set to a nominal desired thickness, and deviations are detected by disturbing a bridge circuit. + or − deviations are read, and

signal lamps light up if the required tolerance is exceeded. An automatic record is possible, the movement of the recording paper being controlled by a pick-up to match the feed rate of the manufactured product.—L. D. H.

Development in Thickness Gauges and Allied Instruments. J. L. Putman. (*Process Control Automation*, 1955, **2**, Nov., 417–421). The present state of development of dimension gauges based on the use of beta and gamma radiators and neutron emitters is outlined. (13 references).—L. D. H.

Some Process Control Problems in the Steel Industry. B. O. Smith and A. P. H. Jennings. (*Process Control.* 1954, **1**, Oct., 13–19). Instrumentation and control are described as applied to roof temperature, air/fuel ratio and pressure control in the open-hearth furnace, measurement and control of zone temperature; air, gas and oil flow, furnace pressure and recuperator temperature in reheating furnaces; and radiation gauging and B.I.S.R.A. automatic gauge control in sheet and strip rolling mills.—L. D. H.

Measurement and Control of Weight—Some Modern Methods. (*Instrument Practice*, 1955, **9**, Dec., 1152–1158). The use of load cells of various types for continuous weighing and automatic control is described.—L. D. H.

Locomotives for Heavy Industry. C. Wordsworth. (*Engineer*, 1955, **200**, Dec. 23, 907). The author discusses the requirements of heavy duty steelworks locomotives and the relative merits of conventional steam locomotives. Diesel mechanical transmission, electric and hydraulic transmission are considered in some detail.—M. D. J. B.

Rail-less Materials Handling in the Iron and Steel Industry. G. A. Cewrien. (*Blad Berg. Vänner*, 1955, **31**, 2, 311–374). [In Swedish]. After brief details of arrangements made in American factories, the author discusses cost reductions inherent in the introduction of mechanical handling. The article is illustrated by 66 photographs showing the use of mechanical handling equipment in various Swedish steelworks.—G. G. K.

LUBRICATION

Application of Industrial Lubricating Oils. A. M. Craig. (*Sci. Lubrication*, 1956, **8**, Jan., 11–16). A brief review is made of non-centralized and centralized (manual and non-circulating and circulating automatic) lubrication systems, including that for pressure lubrication of cold rolling mills.

Trend and Development of Lubricating Engineering in Modern Iron and Steel Industry. H. Tonomura. (*Tetsu to Hagane*, 1955, **41**, July, 813–817). [In Japanese]. A review is made, mainly concerning rolling mills, of oil-film bearings, central greasing systems, plastic laminated bearing and gear lubrication. Most modern works in Japan now have a maintenance department dealing with lubrication problems; the dangers of neglect of lubrication are stressed.—K. E. J.

WELDING AND FLAME-CUTTING

Welding Practice in Blast-Furnace Construction. N. E. Gorozhaninov. (*Stal'*, 1955 (5), 467–468). [In Russian]. The organization of work in the welding of the shell of a 1386 cu. m. blast furnace is described. The organization adopted enabled the productivity of the welders to be increased considerably and the construction-time to be decreased without sacrifice of weld quality.—S. K.

The Problem of Fatigue in Welded Components. Z. Garcia Martin. (*Cien. Tecn. Solda.*, 1955, **7**, Nov.–Dec.). [In Spanish]. A review of the problems and causes of fatigue failure is given, with particular reference to stress-raisers, safety factors and design. Information is given concerning the fatigue behaviour of butt welds in a Spanish steel and, briefly, it is shown that good welds give the material a fatigue resistance which is as good as, or better than, the base metal, and that unmachined welds have a fatigue resistance of about 37% less.—P. S.

Welding of Heat-Resisting Steels and New Possibilities of Application. E. Kauhausen. (*Grosse Schweisstechn. Tagung, Frankfurt*, 1955, 10–16). The weldability of a number of ferritic and austenitic steels was investigated. A metallographic examination gave evidence of microcracking in weld metal. It is shown that ferritic steels can be satisfactorily welded when care is taken with pre-and post heating. Austenitic steels are more difficult to weld.—U. E.

Fumes and Gases Developed during Welding with Lime-Electrodes. K. Kellermann and G. Lehmann. (*Grosse Schweisstechn. Tagung, Frankfurt*, 1955, 7–9). The effect of fumes and gases, which develop when welding with basic lime electrodes, on the health of the operator is discussed.

Hardfacing Applications in the Iron and Steel Industry. M. Birkhead. (*Welding Metal Fab.*, 1956, **24**, Jan., 25–32). The hardfacing of engineering equipment in melting shops, rolling mills and other parts of the iron and steel industry is discussed.—U. E.

The Argonarc Welding Process. (*Torch*, 1955, Autumn Issue (7), 10–13.). The principles and applications of the argonarc process are discussed.—U. V.

Steel Pipe Production Plant. (*Welding Metal Fab.*, 1956, **24**, Jan., 22–24). The extensive use of heavy presses and automatic arc welding is discussed with illustrations.—U. E.

Temper Brittleness of 1% Cr—½% Mo Weld Metal. W. J. Lester and G. R. Prescott. (*Welding J.*, 1955, **34**, Nov., 553s–557s). An investigation is described which dealt with weld failures in one of the first 1 Cr—½ Mo catalytic cracking reactors constructed. Properties of 1 Cr—½ Mo welds made with several types of electrodes are reported and it was found that temper brittleness was the cause for the failure of 1 Cr—½ Mo weld deposit.—U. E.

Investigation of Weld-Metal Cracking in High-Strength Steel. R. P. Sopher, A. J. Jacobs and P. J. Rieppel. (*Welding J.*, 1955, **34**, Nov., 544s–552s). An apparatus is described for studying the basic causes of cracking in high strength weld metals. Hot tension properties and hot-cracking resistance of steels of variable compositions were studied. It was found that in SAE 43XX-type weld metals an increase in carbon, sulphur, and phosphorus contents have an adverse effect on hot tension properties and hot cracking resistance. A slight but definite association was shown to exist between the presence of intergranular eutectics in the tension specimens and poor hot ductility.—U. E.

Lithium Additions to Brazing Alloys. N. Bredzs and D. Canonico. (*Welding J.*, 1955, **34**, Nov., 535s–543s). By comparing some chemical and physical properties of lithium with the properties of some other strongly deoxidizing metals, it is shown that lithium appears to be the most suitable metal for developing self-fluxing brazing alloys. It is found that some additions of lithium not only reduce the oxides on the surface of the steel, but also considerably lower the wetting angle of molten silver.—U. E.

Seam Welding Dissimilar Thicknesses of Low-Carbon Steel. M. L. Begeman, E. J. Funk. (*Welding J.*, 1955, **34**, Nov., 529s–534s). An investigation is reported on proper welding conditions for the lubrication of pressure-tight, seam-welded joints, in dissimilar thickness combinations of low-carbon steel sheets.—U. E.

Consider Sigma—For Faster Weld Speed, Cost Savings. (*Western Metals*, 1954, **12**, Mar., 40–42). The principles of shielded inert gas metal arc (sigma) welding are outlined and the advantages of its higher speed, higher arc-time factor, and freedom from slag and spatter are emphasized. The great advances made with this technique in the aluminium welding field are described.—P. M. C.

There's Lots New In Welding. P. Stern. (*S.A.E.J.*, 1955, **63**, Jan., 46–48). A brief review of recent progress in the fields of resistance welding, equipment and processes, and arc welding electrodes is given.—P. M. C.

Submerged Arc Welding with the Electrode Lying Along the Joint. P. Berthe. (*Soudage Techn. Connexes*, 1955, **9**, Nov.–Dec., 323–324). The Elin Haferguth process is described.—T. E. D.

Metallurgical Aspects of the Arc Welding of Steels for Water Turbine Rotors. S.-E. Erikson. (*Soudage Techn. Connexes*, 1955, **9**, Nov.–Dec., 297–310). The metallurgical problems arising during electric arc welding of steels for water turbines are connected chiefly with the heating and cooling which succeed each other rapidly during welding. The Jominy test does not give sufficient information concerning the microstructure in the zones affected by high temperatures. A new method, using induction heating, is used successfully to examine weldability. Details are given of examination of the microstructure.—T. E. D.

On the Temperature of Droplets of Molten Electrode Metal During Arc Welding. A. A. Erokhin. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955 (9), 125–136. [In Russian]. Calorimetric determination of the temperature of droplets of molten electrode metal at the moment of their separation from the electrode were carried out. Experimental procedure and the apparatus used are described in some detail.—V. G.

Nickel Chrome Brazing of Stainless. R. A. Gustafson. (*Western Metals*, 1955, **13,** Aug., 54–56). The author describes the method used for successful brazing of stainless steel. Brazing compounds of nickel–chrome alloy are applied in paste form, and the parts heated at 2050° F in a dry hydrogen atmosphere. Good mechanical, heat and corrosion resistant properties are achieved in the joints. The furnace equipment is described and illustrated.—P. M. C.

Selection of Electrodes for Manual Arc Welding of Low-Carbon Steel. (*Metal Progress*, 1955, **68,** Aug. 15, 158–168). The selection depends on the quality required in the welded assembly, the equipment available, the weld location, cost, base metal, joint design, and the desired weld properties. The influence of each of these factors and their interrelation as they affect production welding are described.—B. G. B.

Accuracy and Tolerance in Flame Cutting. H. Christoph. (*Grosse Schweisstechn. Tagung, Frankfurt*, 1955, 73–80). The accuracies of flame cutting machines are discussed together with the effect of plate-thickness and length of cut on scatter and tolerances.—U. E.

New Methods of Application of Flame Cutting in the Steel Works and Rolling Mill. H. J. Wernicke. (*Grosse Schweisstechn. Tagung, Frankfurt*, 1955, 80–85). Oxygen cutting machines used in the rolling mill for cutting rolled sheet and the application of powder cutting to the cleaning of castings are described.—U. E

Measures for Improving the Economy of Oxy-Acetylene Cutting. (*Schweissen u. Schneiden*, 1955, **7,** Dec., 504–506). Flame cutting data obtained from various firms are tabulated and the effect of oxygen pressure and speed on the appearance of the surface of the cut is illustrated.—U. E.

A Study on Low-temperature Brazing (IV) The Effects of a Small Amount of P and Ag in Cu–Ni–Zn Alloys on Wettability and Brazed Strength. H. Ishida and S. Yaji. (*J. Mech. Lab., Japan*, 1955, **9,** Sept., 181–185). It was found from experiments that the wetting temperature is lowered, at optimum wettability and brazed strength, when the silver content of an alloy containing 0·5% P is increased.—J. G. W.

Argon-arc Welding Offers Opportunities. T. E. W. Preston. (*Metalworking Production*, 1956, **100,** Jan. 6, 1–8). The article describes British practice in the use of one-side argon-arc spot welding with relevant references to American practice.—M. A. K.

MACHINING AND MACHINABILITY

The Electro-erosion of Metals. H. Opitz. (*Rev. Univ. Min.*, 1955, 9th series, **11,** Nov., 562–568). An account is given of a fundamental investigation of this technique. The relation between the spark frequency, degree of finish and speed of cutting is considered and the metallurgical state of the surfaces is examined in detail. Factors controlling the formation of surfaces with a " super " finish are reviewed.

An Investigation of the Wear of a Cutting Tool Using Radioactive Isotopes. E. P. Nadeninskaya. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954 (1), 24–40). [In Russian]. The choice of a method of activating a cutting tool for the investigation is discussed. Methods and apparatus used for measuring the radio-activity of the wear products is outlined. The results of investigations of the following factors: the influence of cutting time, velocity of cutting, depth of cutting, cutting rate and cooling on the wear of cutting tools are described.—V. G.

Heat Treatment of Steel for Good Machinability. H. Opitz, S. Ammareller and H. Koelzer. (*Metal Progress*, 1956, **69,** Jan., 108–114). Machinability, as measured by cratering on the tool face when cutting a continuous chip, is directly related to shear strength. Suitable heat treatment can minimise cratering and give a smooth surface finish. A number of examples are given.—B. G. B.

Heat Treatment as a Means for Improving Machinability. H. Koelzer. (*Härterei-Tech. Mitt.*, 1953, **6,** (2) (2), 41–59). The influence of heat-treatment on machinability are discussed. A large grain size obtainable at 950° C (for 2 hours), is recommended for some cases only. Improvements in laying down standards are suggested.—R. P.

Cemented Metal Carbides. G. Kihl. (*Jernindustri*, 1955, **36,** Nov., 192–197). [In Norwegian]. Details are given of a test method which distinguishes clearly between poor and high grades of cemented metal carbides for cutting tools. Evolved by the Escher-Wyss Co., the test costs 80 Sw. Fr. to undertake and gives full information regarding mechanical strength, resistance to wear in relation to cast iron and steel, and hardness. It is thus possible to reduce stocks to three different grades, each capable of two or three different functions.—G. G. K.

Electro-Spark Machining of Metals. N. A. Stang. (*Jernindustri*, 1955, **36,** Dec., 214–218). [In Norwegian]. After comparing the future prospects for ultrasonic and electro-spark machining methods, the author describes the design and operation of the Agietron universal spark machining unit. Nine examples are given of typical machining operations.

Devotion to Detail Assures Good Tool Life. S. R. Prance. (*S.A.E.J.*, 1955, **63,** Aug., 19–23). Brief hints are given concerning the points to be considered in order to promote good tool life. The following factors are dealt with: selection of material; hardness and structure of workpiece; decarburization; stress relieving after rough machining; hardening; quenching; tempering; grinding; stress relieving after grinding.—P. M. C.

Electro-Erosive Machining of Metals. W. Ullmann. (*Maschinenwelt Elektrotechnik*, 1955, **10,** Oct., 293–295). Technical data are given of the " Agietron " electro-erosive machining equipment.—L. D. H.

Distribution of Shear-Zone Heat in Metal Cutting. W. C. Leone. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76,** 121–125). An expression is presented for the fraction of thermal energy developed at the shear zone in orthogonal metal cutting which is conducted back into the workpiece.—D. H.

On the Analysis of Cutting-Tool Temperatures. E. G. Loewen and M. C. Shaw. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76,** 217–231). The analytical procedure to be followed in computing cutting temperatures is presented and illustrated by several examples. The relative importance of the variables influencing tool-face temperatures is discussed and those of real significance listed in order of importance.

Use of Liquid Carbon Dioxide Cooling for Turning Operations on Machine Tool Spindles. (*Machinery*, 1955, Dec. 16, **87,** 1428–1431). The article describes a series of four tests carried out on a Churchill-Redman heavy duty copy-turning lathe, using liquid carbon dioxide for cooling the tools. Each test was made on a different steel specification and the results show an increase in tool life of between 100 and 400% over normal soluble oil coolant.—M. A. K.

CLEANING AND PICKLING

Blast Cleaning of Metal Surfaces. O. Peltzer. (*Stahl u. Eisen*, 1955, **75,** Dec. 15, 1681–1691). Sand blasting was invented in the U.S.A. by Benjamin C. Tilghman in 1870, and the author reviews the history of blast cleaning from that time. The present position is discussed, and methods, equipment, and blasting media are surveyed.—A. C.

Formation of Industrial Oxide Layers on Hot Rolled Strip and Plate. W. Fackert. (*Stahl u. Eisen*, 1955, **75,** Dec. 15, 1705–1710). The principal factors affecting the oxidation of steel surfaces are reviewed, and the fundamentals of layer formation are presented. Possible methods are enumerated. A newly developed technique for plotting scale solution curves is described and its application discussed.—A. C.

Cleanability and Oil Spreading Rates. H. B. Linford and P. E. Grubb. (*Plating*, 1955, **42,** July, 895–902). The relation between the rate of spreading of oils and greases on a particular metal and the difficulty of removing the grease from another metal was investigated.—A. D. H.

Abrasive Blasts Scale from Carbon Strip. G. D. Dill. (*Steel*, 1955, **137,** Nov. 28, 106–107).

Boeing Develops Promising Descaling Process for Titanium and Stainless Steel. B. Chambers. (*Western Metals*, 1954, **12,** Sept., 64–65). Two processes have been developed by Boeing Airplane Co., one of which inhibits scale formation on titanium, the other converts normal scale on such steels as AISI 310 to a form which is subsequently more easily removed. Both processes involve treatment of the metal before conventional heat treatment; titanium with a carbonate/nitrate compound, stainless steel with a certain silicon-bearing substance. Scale subsequently formed during heat treatment is then much more easily removable by normal pickling methods. Both processes are patented, and no further details are given.—P. M. C.

Ultrasonics—Answer To Difficult Metal Cleaning Problems. (*Western Metals*, 1955, **13,** Mar., 63–65). The application of ultrasonic energy to the solvent cleaning of metal parts is discussed. The Detrex Soniclean process (U.S.A.) is des-

cribed, in which a ceramic transducer generates ultrasonic waves at a frequency of 400,000 cycles per second in a chlorinated solvent bath.—P. M. C.

Metal Cleaning Costs. (*Metal Progress*, 1955, **68**, Aug. 15, 169–173).

Determination of the Valency of Metallic Ions During Electrolytic Polishing in the Presence of ClO_4' Ions. P. Brouillet, I. Epelborn and M. Froment. (*Compt. Rend.*, 1954, **239**, Dec. 20, 1795—1797). The valency of many metals is stable during electrolytic polishing in the presence of ClO_4' ions, but those which oxidize pass into solution with one or more valencies, some of which are unstable.

Rust Transformers Based on Phosphoric Acid. G. Schultz. (*Metalloberfläche*, 1955, **9**, Dec., 177B–179B). Experiments were carried out to test the efficiency of a number of proprietory rust transformers based on phosphoric acid, using steel sheet. The samples were cleaned to some extent by brushing and lapping, the preparations applied, and the sheet finally lacquered and tested for corrosion resistance. Results were found to be very variable, depending on the condition of the sheet, the type of transformer and the amount used.

Contribution to the De-Scaling of Rolled Material by Means of Flame Cleaning. H. Wiegand, K. Schaar and F. Nieth. (*Metalloberfläche*, 1955, **9**, Oct., 162A–173A). With the object of investigating the possibility of applying flame cleaning to the de-scaling of lighter sections than are normally treated by this process, a number of sheets were rolled in thickness of 5–30 mm, from sheet and slab, in two qualities of steel. The composition of the scale and its degree of removal were established for various thicknesses, and the significance of each factor determined statistically. For sheet of up to 15 mm, the amount of scale removed was directly proportional to the thickness, and only above this thickness was satisfactory removal possible. Strips of scale left between the cleaned portions were attributed to the burner design. Scale removal for a given thickness was more complete with sheet rolled from slab, this result being explained in terms of the composition and distribution of the scale.—L. D. H.

The Condition of the Steel Surface, Using Various De-Rusting and De-Scaling Processes. F. Nieth. (*Metalloberfläche*, 1955, **9**, Oct., 174A–179A). Three pieces of steel sheet, the first with a coating of old rust, the second freshly rusted and the third in the as-rolled condition, with a skin of oxide, were cut into several test pieces, and cleaned by several processes, the surface roughness being then examined by profile photographs. Assuming irregularities greater than $\frac{1}{3}$ of the thickness of paint to be applied as unsatisfactory, all processes except fine sand blasting and flame cleaning were ruled out.—L. O. H.

Influence of Flame Cleaning on the Strength of Constructional Parts. S. Berg and K. W. Sippell. (*Metalloberfläche*, 1955, **9**, Oct., 179A–185A). Test bars either drilled or with a welded joint were subjected to alternating stresses, the results being compared with those on similar flame-cleaned bars. Variations in fatigue strength found were less than those between individual bars; it can be concluded that flame cleaning has no detrimental effect in fatigue strength in these cases.—L. D. H.

Flame Cleaning. K. W. Sippell. (*Metalloberfläche*, 1955, **9**, Oct., 147A–162A). A detailed description and discussion of flame cleaning is given, under the headings of surface treatment and corrosion protection; characteristics of flame cleaning, its siting and operating technique; influence of temperature on normal constructional steels; cost of the process and its range of application.—(53 references).—L. D. H.

The Influence of Deformation on the Effect of the Chemical Polishing of Austenitic Chromium-Nickel Steels. A. V. Krusenstjern and H. Schlegel. (*Metalloberfläche*, 1955, **9**, Oct., 148B–151B). Strip from 18/8 Cr–Ni steel was elongated by 5, 10 and 30%, annealed, cooled with compressed air, pickled and the deformation repeated. This procedure was carried out in three successive treatments on the same sample. The efficiency of a chemical polishing treatment was investigated after each treatment, using a specially-designed polish meter, which is described. Some samples were also tested after removing the surface with fine emery paper. Half of each test piece was polished, and a photomicrograph taken of the polished and unpolished surface and the section in each case. It was found that internal stresses in the micro scale had no influence, but that the alternating deformation and annealing treatments roughened the surface progressively and led to a less efficient polish. Chemical polishing covers minor defects more successfully than electrolytic polishing, due to the polish being more diffuse.—L. D. H.

Electrolytic Processes for Surface Conditioning of Metals. J. W. Cuthbertson. (*Proc. Inst. Elect. Eng.*, 1955, **102**, Part A, Oct., 501–509). The uses of electrolysis for surface cleaning and descaling of metals and the process of electrolytic polishing are discussed. Cathodic processes are in general more efficient and economical than purely chemical treatments, but should be applied with caution to some steels, because of the likelihood of hydrogen absorption. Examples are given of electrolytic pickling of steel, cathodic and anodic treatments being discussed. The mechanism, techniques and economics of electrolytic polishing are dealt with.—(29 references).—L. D. H.

Symposium on Sand and Steel Blasting. Some Considerations on the (Dutch) Order in Council on Sand Blasting. H. 't Hart. (*Metalen*, 1955, **10**, Oct. 15, 407–414). [In Dutch].

Some Considerations on the Cleaning of Metal Surfaces by Blasting and Shaking. A. De Jong. (*Metalen*, 1955, **10**, Oct. 31, 429–430). [In Dutch].

Some Data on the Production and Quality of Coarse Steel Powder. J. J. Ubbink. (*Metalen*, 1955, **10**, Oct. 31, 430–431). [In Dutch].

Technical Problems with Enamelling. A. W. Bruins. (*Metalen*, 1955, **10**, Oct. 31, 431–433). [In Dutch].

Hearth Blasting. J. Slob. (*Metalen*, 1955, **10**, Nov. 15, 451–457). [In Dutch].

Problems Arising when Blasting Thick Steel Plate. P. Staal. (*Metalen*, 1955, **10**, Nov. 15, 452–454). [In Dutch]. Arising out of the (Royal Dutch) Order in Council to forbid in the interests of silicosis prevention, the use of sand for treating the surfaces of materials and its substitution by coarse steel dust or other substance free from crystalline silicon oxide or even other methods, the various papers discuss the possible effects of the decree on the branches of industry concerned. The wording of the Order in Council in question concludes the final article.—F. R. H.

Cleaning of Metal Prior to Phosphating. F. P. Spruance. (*1er Congrès Mondial de la Détergence*, 1954. Section 11, 11–13). Alkali and solvent cleaning are described, and their effects on the phosphating of zinc, galvanised steel, and steel.

Cleansing of Metal Surfaces before Electroplating. M. Ades. (*1er Congrès Mondial de la Détergence*, 1954. Section 11, 7–10). Phosphate and silicate baths are described.

Investigations of Pickling Residues. A. Petzold. (*Metalloberfläche*, 1955, **9**, Dec., 205A–207A). Residues from pickling mild steel in sulphuric, hydrochloric, and nitric acid were investigated. It was found, in agreement with previously published results, that the constituents not readily soluble in the acid are concentrated in the residues. In the case of nitric acid, impurities at the grain boundaries are attacked preferentially, in particular copper and nickel.

Regeneration of Sulphuric Acid Pickling Liquor. J. Roneš. (*Hutník*, (Prague), 1956, **6**, (1), 18–21). [In Czech]. Methods of disposal of spent pickling liquor and processes suitable for recovery of ferrous sulphate and sulphuric acid are surveyed. A nomogram for the determination of optimum conditions of regeneration by the evaporation method, based upon recent Czechoslovak researches, is presented and discussed.—P. F.

Utilization of Waste Pickling Acid in Potable Water Treatment. J. S. Gettrust. (*J. Amer. Water Works Assoc.*, 1955, **47**, Aug., 752–762). The successful use of waste pickling liquor, as a source of iron sulphate, for the purification of drinking water on a commercial scale is described.

PROTECTIVE COATINGS

The Structure and Properties of Electrodeposited Metals. F. Dyngvold. (*Tek. Ukeblad*, 1955, **102**, Nov. 17, 913–918). [In Norwegian]. It is shown that the adhesion of heavy electrodeposited coatings to the underlying surface is governed by the crystalline structure of both metals, whilst hardness and ductility are dependent on plating conditions. Loss of fatigue strength in the base metal can be counteracted by reducing the internal stress in the coating. Details are given of methods available for examining the crystal structure of coatings and of the influence exerted by

plating procedure and base metal on the structure of the coating. It is pointed out that such coatings often have peculiar crystal shapes due to the inclusion of foreign bodies in the lattice.—G. G. K.

A Non-oxidizing Heat Test for Plating Adhesion. I. W. Marcovitch. (*Plating*, 1955, **42**, June, 749–750). The method described consists of using an oil-bath as the heating medium at 475°–500° F wherein defective coatings give rise to blistering.—A. D. H.

Nickel Plating by Direct Chemical Deposition. (*Corrosion Techn.*, 1955, **2**, Dec., 377–379). The development of nickel plating by chemical deposition is outlined and the acid bath and basic bath methods are described briefly and compared. Typical applications of both are given and the use of catalysts and the general precautions to be observed (e.g. prevention of poisoning) are indicated. The article concludes with a consideration of the economics of nickel plating by chemical deposition.—L. E. W.

Iron-Zinc Alloy Electroplating As a Protective and Decorative Finish for Steel. F. W. Salt. (*Electroplating*, 1956, **9**, Jan., 3–5). Plating processes are described for the deposition of alloys containing 6–90% Zn from sulphate baths. Those containing 6% Zn are bright and might be used as a basis for other coatings on account of their smoothing action. With 35%–65% Zn, the coatings are hard, give good adhesion to steel, have a higher corrosion resistance than galvanized coatings and can be deposited at high rates. The 60% Zn alloy can be deposited bright.—A. D. H.

Cadmium or Zinc? E. Snekvik. (*Tek. Ukeblad*, 1955, **102**, Dec. 15, 1020–1022). [In Norwegian]. After reviewing the relative advantages of zinc or cadmium coatings for steel structures subject to corrosion by marine or industrial atmospheres, the author concludes that zinc is better in acid environments, cadmium is superior in its resistance to salt sprays and in extremely moist air accompanied by heavy condensation, whilst in dry inland areas both coatings are equal in effect. Furthermore, in both cases corrosion resistance can be increased by chromatizing without a reduction in anodic protective effects.—G. G. K.

Continuous Hot Galvanizing of Strip. N. E. Cook. (*Metal Finishing*, 1955, **53**, Nov., 67–69, 73). A description is given of the process and plant employed at the Wheeling Steel Corp., W. Virginia. Induction heated pots are used and aluminium is added to the zinc.—A. D. H.

Galvanizing Steel Wire. (*Wire Ind.*, 1955, **22**, Oct., 995–996). The main features of hot-dip galvanizing practice, with particular reference to zinc economy, are outlined. This article is based on information supplied by the Office of Technical Services, U.S.A.—J. G. W.

Zinc Coatings for Protecting Steel. E. W. Horvick. (*Product Eng.*, 1955, **26**, Dec., 158–161). Five different methods of applying a zinc coating are described; and the advantages and disadvantages of each method are discussed, and examples given of the method specified for various conditions.—E. A. C.

Conversion Coatings for Cadmium and Zinc. E. F. Foley, jun. (*Metal Progress*, 1956, **69**, Feb., 86–90). A conversion coating is an inorganic coating other than a metal; chromates, phosphates, molybdates, and sulphides are in common use. They improve corrosion resistance, produce attractively coloured surfaces and increase the adhesion of subsequent organic coatings. Conversion coatings on zinc and cadmium are primarily discussed.—B. G. B.

Standards and Requirements in Electroplating. E. Snekvik. (*Tek. Ukeblad*, 1955, **102**, Oct. 27, 849–856). [In Norwegian]. Extracts are presented from Norwegian standards for electroplating and details given of the importance of coating thickness in regard to resistance to abrasion and corrosion. A comparison is made between American, British, German, and Swedish specifications for chromium, zinc, nickel, and cadmium plating and details are given of Danish regulations governing the nickel and chromium plating of automobile components.—G. G. K.

'Porus-Krome' Hardening of Engine Cylinders against Corrosion. (*Corrosion Techn.*, 1956, **3**, Jan., 17–18). The operations involved in the 'Porus-Krome' process and its applications are outlined, after first discussing the causes of cylinder bore wear and the protection afforded by chromium plating.—L. E. W.

Electrolytic Nickel Deposits from Chloride and Sualphte Solutions. E. Raub. (*Metalloberfläche*, 1955, **9**, June, 88A–92A). The difference in behaviour of nickel chloride and sulphate electrolytes is discussed, and explained in terms of the higher dissociation and hydrolysis constants of nickel chloride.

Barrel Plating Setup Combines High Output with Versatility. G. W. Harding. (*Iron Age*, 1955, **176**, Dec. 29, 65–67). A batch zinc-plating plant is described, which can handle 20,000 lb worth per hour. Simple controls allow the plating specification to be changed at will, and the entire system is automatic.—D. L. C. P.

"Cold Galvanising"—A Noteworthy New Means of Surface Protection. I. C. Fritz. (*Werkstoffe Korrosion*, 1955, **6**, Nov., 521–523). The merits of "cold galvanizing"—i.e. of "zinc-rich" paint—are discussed and compared with those of coatings of solid metallic zinc applied by hot-galvanizing, sherardizing, electrodeposition or spraying.—J. C. H.

Canadian Tinplate: Electrolytic Lines Replace Older Hot Dip Methods. J. D. Harbron. (*Iron Steel*, 1956, **29**, Feb., 49–50). Canadian tinplate is now manufactured by the continuous electrolytic method, resulting in thinner and more uniform tin coatings. Details are given of the economy achieved.—G. F.

Alloy Plating Can Give Your Products New Appeal. F. A. Lowenheim, R. T. Gore. (*Iron Age*, 1955, **176**, Dec. 22, 67–70). Examples of the growing practice of alloy plating are given. Properties and advantages of the coatings are noted.

Electroplating on Porous Metal. J. B. Mohler. (*Metal Finishing*, 1955, **53**, Nov., 70–73). Methods of obtaining acceptable deposits on porous metal including powder metal compacts are described and the causes of porosity in deposits are discussed.—A. D. H.

Attack of Molten Zinc Saturated with Iron on Iron Containing Sulphur and Phosphorus. D. Horstmann. (*Arch. Eisenhüttenwesen*, 1955, **26**, Oct., 577–581). Investigations carried out on iron with high sulphur and phosphorus contents show that the attack by iron-saturated molten zinc is mild for a sulphur content of 0·1%, but about 30% stronger for the same content of phosphorus. For pure iron the attack progresses linearly with time in the region 495–515°, but this temperature range is somewhat broadened by the presence of sulphur and phosphorus. For higher phosphorus content the attack becomes very heavy in this temperature range. Thus, for phosphorus contents of 0·085, 0·280, and 0·017% at 500°, the rates are respectively 12·2, 17·7, and 7·3 × 10^{-4} g/cm² min.—A. C.

The Selection of Electroplated Coatings. (*Metal Progress*, 1955, **68**, Aug. 15, 97–105). Protective and protective/decorative coatings and special purpose coatings are reviewed. All the metals commonly used as coatings are considered and examples of applications of each coating are given with an indication of the factors which determine the selection.

Disposal of Toxic Effluents. Handling Acids and Cyanides. (*Engineering*, 1955, **180**, July 8, 58–59). This article describes a new method of effluent disposal developed by the British Thomson-Houston Co., Ltd. to neutralize toxic effluents from their plating and pickling plant.—M. D. J. B.

Coated Steel Sheet: Challenge of Alternative Materials. S. S. Carlisle. (*Iron Coal Trades Rev.*, 1956, **172**, Jan. 13, 75–83). As a basis for assessing the strength of competition from other sheet materials so as to guide steel coatings research into the most profitable channels, the author discusses the uses and quantities produced of tinplate, galvanized sheet, and uncoated sheet steel, and reviews existing or potential alternative materials. These include aluminium, aluminized steel, terneplate, asbestos-cement sheets, vitreous enamelled steel sheets, plastic sheets, plastic-coated steel, and metal alloy coatings.

Protection of Low-Strategic Alloys with a Chromium–Boron–Nickel Cermet Coating. D. G. Moore and J. R. Cuthill. (*Amer. Ceram. Soc. Bull.*, 1955, **34**, Nov., 375–382). A new application procedure is described whereby a cermet layer can be deposited on a metal or alloy surface by using standard ceramic coating techniques. The novel feature of the process is the fluxing action of the frit admixture which permits welding of the cermet particles to occur during firing, without the necessity of a highly purified atmosphere. Coatings have excellent thermal shock resistance, are reasonably ductile, and give good oxidation protection up to 1500° F.—D. L. C. P.

Contribution to the Metallography of Lead Coatings on Steels. J. Teindl and L. Bezecný. (*Hutnické Listy*, 1956, **11**, (1), 18–21). [In Czech]. The lead coating processes used in Czechoslovakia is described, and the structures and faults in coated sheet are discussed on the basis of micrographs. For

certain applications electrolytic coating followed by passivation of the lead is recommended.—P. F.

Brass Plating from Cyanide-free Alkaline Solutions. S. K. Ray, H. V. K. Udupa, and B. B. Dey. (*J. Sci. Indust. Res.*, 1955, **14B**, Dec., 652–655). A description is given of the influence of current density on deposits of brass obtained from alkaline solutions of copper sulphate and sodium zincate in glycerine.—E. E. W.

The Electrodeposition of Tungsten. G. L. Davis and C. H. R. Gentry. (*Metallurgia*, 1956, **53**, Jan., 3–17). Thick coherent layers of pure tungsten have been deposited from fused salt baths containing borates and tungstic oxide. The equipment used is described and theoretical aspects of electrodeposition from fused salt baths are considered in detail. (49 references).

Aluminium Curbs High Temperature Erosion. W. G. Patton. (*Iron Age*, 1956, **177**, Jan. 12, 74–77). The operation of an automatic production line for aluminium spraying alloy-steel engine valves is described. The operations involve pre-heating by induction, aluminium flame spraying, and an alloying induction heat treatment. Output is 4000 parts per hour.—D. L. C. P.

Coating on Polished Strip Saves Refinishing Costs. W. G. Patton. (*Iron Age*, 1955, **176**, Nov. 24, 83–85). The coating material, "Mar Proof," is applied to polished strip as protection during forming and handling operations; the film can then be removed by alkali cleaner leaving a good surface. For stamping operations it is used in conjunction with a special lubricant.—D. L. C. P.

Electrical Inspection of Steel Pipe Coatings. S. M. Davidson. (*J. Amer. Water Works Assoc.*, 1956, **48**, Feb., 121–130). Electrical tests to measure the soundness of coal tar–enamel anti-corrosion coatings on steel pipe are described.—B. G. B.

Design of Steel Pipe with Cement Coating and Lining. E. S. Cole. (*J. Amer. Water Works Assoc.*, 1956, **48**, Feb., 131–138). A short account of the design of this type of pipe with diameters of 30 in. or larger is presented.—B. G. B.

What is Known about Molybdenum Spraying. Sheila M. Holgate. (*Lastechn.*, 1955, **21**, Dec., 228–231). [In Dutch]. After calling attention to the precautions to be observed when spraying with molybdenum, the article gives particulars of suitable pressures of the oxy-acetylene gases in the spray gun and the film thicknesses to be applied. Owing to its hardness and high adhesion, a molybdenum under-film forms an excellent anchor for upper coatings of less costly metals. It is concluded that molybdenum offers little advantage as regards resistance to corrosion or to the effects of high and low temperatures. Owing to its microporosity, the metal can prove useful in providing under-films on smooth hard surfaces that must not be machined or roughened prior to the application of coatings of other metals. It is pointed out that care is necessary with steels liable to fatigue phenomena and this question is being studied. Several micrographs appear. (7 references).—F. R. H.

Metal Spraying Flat Surfaces. (*Electroplating*, 1956, **9**, Jan., 19–22). The recommended methods of the American Welding Society for spraying ferrous and non-ferrous metals on flat surfaces are summarized and compared with British practice.—A. D. H.

Process Aluminizing of Automotive Valve Heads for Oxidation Resistance. (*Indust. Heating*, 1956, **23**, Jan., 42–46, 50). The "Alspray" process in which a sprayed coating of aluminium is bonded to valve stems by rapid melting in a salt bath is described.—A. D. H.

Some Fundamental Aspects of Frit Formulation. N. S. C. Millar. (*Inst. Vitreous Enamellers Bull.*, 1956, **6**, Jan., 82–89). Basic principles involved in formulating frits are reviewed with reference to the physical properties required. The role of opacifiers is discussed in detail.—A. D. H.

Statistical Quality Control for Enamelled Steel Production. J. Bevan. (*Amer. Ceram. Soc. Bull.*, 1955, **34**, Oct., 340–341). A statistical quality control programme for a plant manufacturing pressed steel bathtubs is given. Detailed records are made of all defects in materials and processing.—D. L. C. P.

Testing the Thickness of Passivated Zinc Coatings. M. E. Gol'dshtein. (*Zavodskaya Laboratoriya*, 1955, **21**, (2), 204). [In Russian]. A brief account is given of a comparison of various methods used for determining the thickness of ordinary and passivated zinc-coating in galvanizing. Best results are obtained by the electromagnetic method, which is not affected by passivation.—S. K.

Electro-Zinc Coated Steel Sheet and Strip. D. A. Winton. (*Corrosion Prevention and Control*, 1956, **3**, Feb., 45–46). The author outlines the electrodeposition process and discusses briefly the properties and applications of electro-zinc coated steel.—L. E. W.

An Investigation of the Processes taking place during Hot Tinning of Steel Sheets. I. A. Kakovskiĭ and N. S. Smirnov. (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1955, **12**, 48–57). [In Russian]. It was shown that wetting of sheets by molten tin is the basic process on which all further effects (diffusion of tin into iron, uniformity of tin layer) depend. Lead was found to be a surface-active admixture in tin, it improves wetability of steel sheets by tin, and decreases the induction time. Copper and iron in tin (the latter as a suspension of crystals of $FeSn_2$) have the opposite effect. Flux (a solution of zinc chloride) used in tinning has a deciding influence on the wetability of iron by tin, it decreases the induction time to below 0·3 sec.—V. G.

Simple Test Checks Aluminium Coating Uniformity. H. J. Wittrock. (*Iron Age*, 1956, **177**, Feb. 16, 102–103). A simple dip test, developed by Kaiser Aluminium Co., is described for checking the uniformity and thickness of aluminium coatings on steel, using a hydrofluoric acid–copper fluoride solution.—D. L. C. P.

Plastic Coatings for Corrosion Prevention. G. A. Curson. (*Corrosion Prevention and Control*, 1956, **3**, Jan., 30–34). The author discusses the applications and limitations of Polythene, Nylon, Thiokol, and Shellac as corrosion prevention coatings.—L. E. W.

Modern Surface Treatment of Metals by Means of Lacquer Spraying. H. Anders. (*Metalloberfläche*, 1955, **9**, Dec., 180B–183B).

Use of Heavy Cutback Asphaltum Mastic Coatings in Coke Plant Areas. A. H. Bagenstose, Jun. (*Iron Steel Eng.*, 1955, **32**, Sept., 75–78). This article describes mastic coatings as a protection for metal, a weather and vapour barrier for thermal insulation and a waterproofing for masonry buildings in coke plants.—M. D. J. B.

Metal Spraying by the Wire Process. H. J. Plaster. (*Brit. Welding J.*, 1956, **3**, Mar., 73–77). Methods of application, the equipment (hand and automatic), anti-corrosive coatings, and building up of worn parts are described.—U. E.

The Repair of Worn or Over-Machined Parts by Metal Spraying. J. F. Atwell. (*Engineer, Foundryman*, 1955, **20**, Nov., 53–57). The uses and technique of metal spraying are discussed.—A. D. H.

Flame Spraying Coats "Hot" Metal Surfaces to Withstand High Temperature and Shock. A. Pechman. (*Western Metals*, 1954, **12**, Apr., 58–60). Ryan Aeronautical Co., U.S.A., have successfully developed a method for flame spraying cermets on to components for jet and rocket engines. The cermet, a nickel-magnesia combination, is liquefied and applied through a spray gun. Coatings of one thousandth of an inch thickness have given very good high temperature service.—P. M. C.

Vacuum Metallizing Process Gives High Lustre, Cuts Costs. C. Klinefelter. (*Western Metals*, 1954, **12**, Sept., 50–52). A process is described whereby die castings, glass, plastics and textiles are given a very thin "plate" of aluminium, cadmium or zinc. The coating of metal, which seldom exceeds five millionths of an inch thickness, is deposited under vacuum from a molten source. After lacquering, the finish is highly decorative and lustrous.—P. M. C.

Limitations in the Application of Metal Spraying. H. von Hofe. (*Schweissen u. Schneiden*, 1954, **6**, Special Issue, 180–188). The metal spray process and its applications are discussed in detail.—U. E.

Relations of Compositions to Viscosity of Enamel Glasses. T. B. Yee, J. S. Machin and A. S. Andrews. (*J. Amer. Ceram. Soc.*, 1955, **38**, Oct., 378–382). The change in the viscosities of a series of enamel glasses which were produced by varying the CaF_2, Fe_2O_3, TiO_2, Co_3O_4, NiO, MnO_2, $FeSO_4$, and $NiSO_4$ contents were examined over a range of temperatures which correspond approximately to normal firing temperatures. Similar studies on the variations in viscosity produced by blending selected hard and soft frits are reported.—D. L. C. P.

Determination of Strains on Enamelled Cast Iron. J. F. Wuellner and B. J. Sweo. (*J. Amer. Ceram. Soc.*, 1955, **38**, Nov. 404–407). A method of determining strains in enamelled cast iron using a modification of the split ring furnace, and employing cantilever type specimens is described. Strain

curves are compared with results obtained on split rings and the modified method is shown to be the more informative.

Colour Stability of "Fritted-In" Coloured Enamels. N. S. C. Millar. (*Metal Finishing J.*, 1955, **1,** Nov., 483–488). The development of coloured enamels by smelting chromium, cobalt, manganese and nickel oxides into titanium frits is described. The influence of variation in frit composition was investigated.—A. D. H.

Hydrogen Permeability of Steel and its Relation to Enamellability. Y. Lindblom and S. E. Dahlgren. (*Metal Finishing J.*, 1955, **1,** Dec., 517–526). The variation of hydrogen permeability of mild steel measured at 40°C. was measured. It was found that no relationship existed between permeability and gas content, metallographic structure, analysis and adherence of the enamel.—A. D. H.

Causes of Defects in Enamelling of Steel. O. Krüger. (*Neue Hütte*, 1955, **1,** Dec., 97–104). Porosity and blistering of enamels may be due to defects of the steel, such as fissures, slag occlusion, or scale.—L. J. L.

Enamelling with Powder on Iron Surfaces. (*J. d'Inf. Tech. Indust. Fonderie*, 1955, Sept., 5–8). The preparation of the iron surface before enamelling is of particular importance. Details are given of a satisfactory method of preparation. Factors influencing the adherence of the coating are discussed and an apparatus for measuring the resistance of the coating to mechanical shock is described.—B. G. B.

Development of Marine Paints: Recent Progress. A. D. C. Hamilton. (*Indust. Finishing*, 1956, **9,** Jan., 313–315). A review is given of painting compositions and metal pretreatment, with illustrations of corrosion effects.

POWDER METALLURGY

The Behaviour of Spherical Metal Powders in Pressing and Sintering. E. Pelzel. (*Z. Metallkunde*, 1955, **46,** Nov., 813–817). Expressions are derived for the relations between porosity and the sum of the surfaces of contact with increasing pressure, with spherical grains and the results compared with practical observations on pressed and sintered metal powders. A hollow spherical iron powder and a solid grain powder were manufactured, and were strongly corroded by exposure to moisture for several weeks. The powders were pressed into bars and sintered at 1200° C in a current of hydrogen. Except at high pressures, the porous material showed lower strength; at the highest pressures and lowest porosities the strength of both powders coincided with that of compacted iron.—L. D. H.

Manufacture of Metal Powder, Especially Iron Powder. K. C. Wasberg. (*Tidsskr. Kjemi, Bergvesen Met.*, 1955, **15,** (7), 112–123). [In Norwegian]. The uses, properties and manufacture of various metal powders are described. Main stress is laid on the materials and processes used for producing iron powder, together with an analysis of possible markets—especially in the U.S.A.—and potential Norwegian production capacity.—G. G. K.

Thermal Dilatation and Contraction of Polycrystalline Sintered Powder Bodies. K. Kohler. (*Metall*, 1956, **10,** Jan., 21–29). In experiments on the thermal expansion coefficients of a range of metals in the form of sintered powder compacts, the effects of polymorphy, dehydration, size and shape of grains, internal surface area, volume of absorbed gases, compacting pressure and direction of application of pressure, were ascertained at medium and high temperatures. In the case of iron powders the expansion coefficient was a maximum at 600° C. The results of measurements are tabulated in detail.—J. G. W.

Adding Copper to Iron Powder Compacts. P. U. Gummeson and L. Forss. (*Precision Met. Mold.*, 1955, **13,** Nov., 44–45, 83–84). The factors influencing dimensional changes of sintered iron–copper compacts have been reviewed and the results of a number of practical tests reported. The factors causing growth and shrinkage during sintering have been considered separately and a possible theoretical approach to the subject suggested. Special consideration has been given to the case where the copper addition is below the solubility limit of copper in iron at the sintering temperature and it is shown that the dimensional changes are closely related to the particle characteristics of the powder and the duration of the liquid phase.—D. H.

Mond Carbonyl Iron Powders. (*Mond Nickel Co.*, Pamphlet 704, 1954, 1–50). The preparation, properties and application of powdered iron made by the carbonyl process by the Mond Nickel Co. are described in detail. (35 references).

PROPERTIES AND TESTS

Thermodynamic Analysis. III. Automatic Recording of Heat Content Curves of Metals and Alloys. W. Oelsen. (*Arch. Eisenhüttenwesen*, 1955, **26,** Sept., 519–522). A simple arrangement is described for recording heat content curves for thermodynamic analysis.—A. C.

Heat Content and Mechanical Properties of Metals. K. A. Osipov and S. G. Fedotov. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (2), 98–104). [In Russian]. An attempt to correlate heat content and mechanical properties of metals is described. It is shown that mechanical properties of metals including resistance to plastic deformation can be evaluated on the basis of energy required to heat a given metal from a given temperature to the melting temperature and to melt it at this temperature, i.e. by the differences in the heat content. (30 references).—V. G.

Limitations of Steel Specifications. E. H. Snyder. (*Metal Progress*, 1955, **68,** Nov., 76–80). The specifications used for steels are discussed and it is considered that in some cases they can be misleading as though they limit the range of the most important elements or properties, the range is often too wide or some unmentioned property can cause processing difficulties.—B. G. B.

Reversers for a Type IM-12A Tensile Machine for the Investigation of the Main Forms of Loading. N. G. Elizarov. (*Zavodskaya Laboratoriya*, 1955, **21,** (7), 863–864). [In Russian]. Attachments for extending the applicability of a tensile machine to compression, shear, torsion, and transverse bending are described.—S. K.

Bringing Order into Production Control. (*Zavodskaya Laboratoriya*, 1955, **21,** (6), 634–637). [In Russian]. Examples are taken from current Soviet control practice in ferrous metallurgy to show that testing is often carried out unnecessarily.—S. K.

Results of Service Tests of IMCh-30 Universal Hydraulic Machines. G. Z. Zaĭtsev. (*Zavodskaya Laboratoriya*, 1955, **21,** (6), 749–750). [In Russian]. Extensive tests in which the performance of three types of IMCh-30 universal hydraulic testing machines were studied are briefly reported.—S. K.

New and Improved Metallurgical Techniques. C. Sykes. (*J. Inst Metals*, 1955–56, **84,** Apr., 287–290). A brief account of new and improved techniques and apparatus for testing that have become available to the metallurgist in the last 20 years is given.—B. G. B.

How Statistical Techniques Solve Metal Working Problems. C. R. Smith. (*Metal Progress*, 1956, **69,** Feb., 81–86; Mar., 76–78). The use of simple statistical techniques to analyse experimental data is described. Two examples are given which show how the best methods of processing titanium were selected with a minimum of expense. An example of the design of an experiment is also given.—B. G. B.

The Yield Rate of Mild Steel. F. Forscher. (*Amer. Soc. Test. Mat. Bull.*, 1955, Apr., 63–67). The results of experiments to study the yield rate of mild teel under various stresses and temperatures are discussed in terms of nucleation and growth of Lüders bands.—B. G. B.

The Influence of the Method of Steelmaking on the Drawability and Mechanical Properties of Mild Steel Wires. O. Modráček. (*Hutnické Listy*, 1955, **10,** (12), 715–720). [In Czech]. Experiments on the influence of the use of oxygen in steelmaking on the yield stress, work-hardening and ageing properties of basic converter and open-hearth steels containing 0·10% C are reported. The use of oxygen leads to an improvement in these properties regarded from the point of view of wiredrawing. The converter steel, however, aged more rapidly than corresponding steels made by the open-hearth process.—P. F.

Acoustic Method for Determining the Modulus of Normal Elasticity. A. I. Moiseev and M. V. Yakutovich. (*Zavodskaya Laboratoriya*, 1955, **21,** (2), 216–218). [In Russian]. In the apparatus described the modulus of elasticity is determined by a dynamic method, the test-piece being caused to vibrate by a stream of cold or hot air. The frequency is found by comparison with the signal from an audio-frequency generator. The test-piece, in a special holder, can be cooled or heated. Results obtained for a single crystal of transformer steel at temperatures from − 180° to 600° C are presented. The

apparatus is simple, and, with carefully prepared and measured test-pieces gives relative errors of only 2·8%.—S. K.

On Localised Development of Plastic Deformation in Low Carbon Steels. V. I. Trofimov (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1955, **11**, 58–61). [In Russian]. During tensile tests of steel specimens plastic deformation is developed initially in a small part of the volume which subsequently increases. An effort was made to determine the size of sectors affected by plastic flow in strained specimens from mild steel. The influence of rate of loading and the state of the surface of specimens on the size of zones of plastic flow was also investigated. An analysis of elastic-plastic work of steel columns tested during the last 5 years in the Ts N I P S was carried out.—V. G.

On Inertia in Plastic Deformation of Steel. E. Giessmann. (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1955, **11**, 50–57). [In Russian]. During tensile strength tests at high speeds, some anomalous elongations were observed. These are explained by inertia in the propagation of plastic deformation.

Investigation and Calculation of the Remaining Tensile Strength in Wire Ropes with Broken Wires. W. Davidsson. (*Acta Polytechnica, Mech. Eng. Series*, 1955, **3**, No. 6). A method is given for calculating the weakening due to wire breaks and wear, of the tensile strength of a rope whilst in use. The occurrence and distribution of wire breaks not accessible to visual inspection was investigated on various discarded ropes, and it is advised to choose the rope lay as the control length.—J. G. W.

The Predetermination of Tensile Strength in Steel Wire Manufacture. C. Coates. (*Staff School, Fred. Smith & Co.*: Lecture—Feb. 1, 1956). The following causes of the variation of tensile strength of patented and hard-drawn high-carbon steel wire, as between batches, are described in a general manner:—small variations of carbon content, insufficient control of furnace temperature and wire speeds in strand patenting, variation of drawing speed and of drafting.—J. G. W.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf: Relations Between the Ageing of Steels and their Contents of Accompanying Elements. H. J. Wiester. (80–85). The author discusses the effects of N, Al, Mn, Si, P, and S on the strain ageing of steels. The phenomena of strain ageing, quench ageing, and brittle fracture are compared.

Technical Sessions in Liège: Influence of Vanadium upon the Creep and Rupture Strength of Low Alloyed Steels for Tubes. O. L. Bihet. The author presents research results showing the improvement in creep properties of chrome–molybdenum tube steels effected by vanadium additions, probably because of secondary hardening.

Technical Sessions in Paris: Some Research Work Made in France on Impact Strength and Brittle Fracture. R. Borione. A summary is given of recent French research on factors related to impact strength and brittle fracture. Published work by Seferian and Moneyron, Pomey, and Castro and Guessier, and work carried out by IRSID and by Institut de Recherches des Constructions Navales, is reviewed. **Supersonic Testing of Heavy Forgings and Castings.** J. Pignet and E. de Kerversan. Referring particularly to American methods, the authors outline their experiences with ultrasonic testing of heavy forgings and castings. Their interpretation of the oscillograms and subsequent decisions are discussed. **Hydrogen in Steel.** J. Calmettes and R. Ferry. The authors first describe the vacuum-heating method of hydrogen determination and discuss some of the factors affecting its accuracy. Secondly, the effects of the various stages of the steelmaking process on the hydrogen content are considered.—G. F.

Apparatus for the Measurement of the Internal Friction of Metals in Transverse Vibration. B. S. Berry. (*Rev. Sci. Instruments*, 1955, **26**, Sept., 884–887). The apparatus, incorporating a piezoelectric pump serving as an exciter and detector, is used for the measurement of the internal friction of vertically-suspended specimens vibrating transversely *in vacuo*. The total external loss rarely exceeds 5% of the observed internal friction.—L. D. H.

Magneto-Elasticity of Polycrystalline Iron and Nickel. V. Narasimhan. (*Indian J. Phys.*, 1955, **29**, Jan., 27–37). The expression for the change in Young's modulus of a ferromagnetic body, derived from Akulov's theory, is extended to the case of the rigidity modulus. Experiments with soft iron and nickel, in a static method, give results agreeing with those predicted. (14 references).—K. E. J.

Measurement of Tenacity. P. Azou. (*Chim. Analy.*, 1956, **38**, Mar., 75–86). The real meaning of tenacity is examined theoretically, and a definition is given. A method of measuring tenacity is described, and the influence of various factors is reported.—T. E. D.

Discontinuous Elongation of Austenites Subjected to the Ordinary Tensile Test at High Temperatures. X. Waché. (*Compt. Rend.*, 1955, **240**, May 9, 1892–1894). The results of tensile tests on austenitic alloys at high temperature are discussed. The phenomenon of discontinuous elongation is evidence of a phase not in physicochemical equilibrium and hence related to the instability of the alloy. A recording spring-dynamometer was used to plot the relationship between the elongation and the applied load at various temperatures up to 800° C.—G. E. D.

Influence of Rate of Deformation on the Mechanical Characteristics of Steel Obtained in Tensile Tests. F. F. Pedanov. (*Zavodskaya Laboratoriya*, 1955, **21**, (7), 847–849). [In Russian]. Experiments are described in which test-pieces of three steels were subjected to tensile tests with deformation speeds varying from 2 to 60 mm per sec. The effects of these variations on the test results are shown.—S. K.

Behaviour of Welds between Rolled Steel Sections and Steel Castings during the Pulsating Tensile Test. K. Wellinger and P. Gimmel. (*Schweissen u. Schneiden*, 1955, **7**, Dec., 496–503). An investigation is reported on the behaviour of fillet and butt welds between a steel casting and rolled steel section when subjected to the pulsating tensile test. The pulsating tensile strength of the fillet and butt welds was found to be about 18–24 kg/mm² while that of the steel casting alone was 20 kg/mm². The lower load limit was 1 to 2 kg/mm².—U. E.

Effects of Skewing of Test-Pieces on the Endurance Strength of Alloys. M. V. Pridantsev and G. V. Estulin. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 718–721). [In Russian]. An account is given of an investigation of the effect of a small non-alignment of a test-piece on the time required to fracture it by a tensile load at high temperatures. Skewing by as little as 1·5° was found to reduce the time greatly, the effect being most marked with relatively hard and coarse-grained alloys. With skewing the sensitivity to notching also increased. These effects in certain high-temperature alloys are attributed to insufficient reserves of plasticity. Skew high-temperature tensile tests are useful as additional parameters for characterizing the suitability of alloys for high-temperature service under complex loads.—S. K.

Semi-Automatic Grips. M. A. Shchurenko. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 625). [In Russian]. A brief account is given of a semi-automatic device for gripping cylindrical tensile test-pieces with heads.—S. K.

Tests with Chromium–Manganese Case-Hardening Steels. W. Breuer. (*Härterei-Tech. Mitt.*, 1952, **8**, (1), 24–32). The bending test and notched-bar impact test on modern Cr–Mn case hardening steels show great variations. These are caused by differences in grain size of the austenite during hardening. Small grain size is recommended for structural steels but large grain size is preferred for static properties.—R. P.

Device for the Bend-Testing of Grey Iron Specimens. N. I. Bulakh. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 741–742). [In Russian]. A simple device for the bend-testing of cylindrical grey-iron test-pieces is described.—S. K.

Method of Evaluating the Sensitivity of Materials to Cracks. B. A. Drozdovskiĭ and Ya. B. Fridman. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 579–589). [In Russian]. The bend-testing of specimens of constructional steels having previously-generated cracks is described, the effects of cracks of different origin being compared. In the main part of the investigation the cracks were produced by repeated impact loading. Here it was found that the order of the various materials tested differs depending on whether the parameters are, on the one hand, the breaking load and the work of deformation in static bending or, on the other, the toughness and plastic properties in tension. A given material could, when cracked, fail at a lower static load than one less tough and similarly cracked. In high-strength steels the sensitivity to cracks could be especially pronounced and differ greatly from heat to heat, and for these the use of cracked test pieces is particularly advisable. For crack-sensitive steel there was a certain depth of crack which, for a given form of test-piece, led to a sharp fall in the breaking bending load. Other methods of producing cracks were: single-loading and cathodic-hydrogen cracking, but the corresponding results were less reproducible than with

repeated impact-loading. All the methods led to concordant breaking-load values if the sharpness of the crack and, particularly, its direction relative to the greatest normal stress in bending are the same.—S. K.

New Machine for the Torsion Testing of Wire. A. A. Prus. (*Zavodskaya Laboratoriya*, 1955, **21**, (4), 489). [In Russian]. A brief account is given of a new torsion testing machine for wire which automatically records torque against angle of twist and has an improved system for measuring the deformation.—S. K.

The Stress-Corrosion Cracking of Austenitic Stainless Steels. Part II—Fully-Softened, Strain-Hardened, and Refrigerated Material. J. G. Hines and T. P. Hoar. (*J. Iron Steel Inst.*, 1956, **183**, 166–172). [This issue].

Dynamic Determination of the Compressibility of Metals. R. W. Goranson, D. Bancroft, B. L. Burton, T. Blechar, E. E. Houston, Elisabeth F. Gittings, and S. A. Landeen. (*J. Appl. Phys.*, 1955, **26**, Dec., 1172–1179). Equation of state data have been determined by measuring shock and free surface velocity in a plate stressed by high explosive detonation. A limitation is necessary for steel where an elastic wave of compression moves with a higher velocity than the shock wave up to a certain pressure which depends on the dynamic yield point.—E. E. W.

Effects Produced by Explosives with Lined Cavities in Steel. S. Singh and P. H. Gandhi. (*Research*, 1956, **9**, Feb., 55–61). A description is given of the changes in microstructure and microhardness and the types of fracture produced in massive medium-carbon steel targets by jets from high explosive charges in copper-lined conical cavities (" shaped charges "). From the experimental observations, a mechanism of formation is established for the crater in the target. (17 references).

Georges Charpy: 1864–1945. E. N. Simons. (*Brit. Steelmaker*, 1955, **21**, Dec., 402–403). A brief account is given of the work of Georges Charpy. Particular attention is given to the Charpy impact test, which is compared with the Izod test.—G. F.

The Mechanism of the Fracture of Specimens with the Standard Notch During Impact Bending. B. S. Kasatkin. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (7), 75–83). [In Russian]. The mechanism of the formation of fractures under impact bending was investigated on specimens from MSt–3 hot rolled low carbon steel. On the basis of metallographic and X-ray studies of fractures, a mechanism for their formation is postulated.—V. G.

Resistance to Wear and Residual Stresses in Metal. P. E. D'Yachenko and T. V. Smuchkova. (*Izvest. Akad. Nauk, S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (4), 73–79). [In Russian]. The influence of residual stress in the surface layer of steel specimens (caused by mechanical working) on their wear, and changes in the residual stresses and work hardening of the surface layer during the process of wear were investigated. In the discussion of results obtained it is stressed that the relationships found are valid only for the experimental conditions used in the work.—V. G.

Defects of the Type IMCh-30 Hydraulic Universal Testing Machine. R. A. Kuznetsov. (*Zavodskaya Laboratoriya*, 1955, **21**, (2), 254). [In Russian]. Some defects in a new testing machine first produced in 1953 are briefly discussed.

Comparison of Stress-Relaxation Criteria Obtained with Ring-shaped and Cylindrical Test Pieces. V. V. Burduksiĭ. (*Zavodskaya Laboratoriya*, 1955, **21**, 226–228). [In Russian]. Tests with cylindrical and ring-shaped test pieces of an austenitic steel at 600° C and initial stresses of 15 kg/sq mm in which relaxation criteria were determined are described, and the significance of the results assessed.—S. K.

Method of Pre-Treatment in Stress-Relaxation Tests. Ya. S. Gintsburg. (*Zavodskaya Laboratoriya*, 1955, **21**, (2), 223–226). [In Russian]. The pre-treatment method developed in relaxation tests enables the suitability of steel for service under conditions of relaxation of bolted joints and springs to be evaluated. The technology for the production of the steel part and its pre-treatment can also be selected. The duration must be kept as short as possible; it is determined from experimental data of pre-treatments of 1 hr. and over, increasing with temperature. The pre-treatment stress is selected in relation to the service temperature of the steel being investigated.—S. K.

Long-Term Rupture Tests on Metals. L. Ya. Liberman. (*Zavodskaya Laboratoriya*, 1956, **21**, (2), 218–222). [In Russian]. The Larson–Miller relation $T°k$ (C + ln time to rupture) = const. was found to hold for many alloy steels. This parameter was satisfactory for accelerated tests of the long-term strength. The tests were carried out at a higher temperature than required and the value for the required temperature was calculated from the above relation, in which C is generally in the range 18–22. The percentage error liable to result from the use of the relation for various steels is considered. The relation between the parameter and the stress for pearlitic and austenitic steels is plotted.—S. K.

Formula for Determining Resistance to Fracture. P. S. Sokolov. (*Zavodskaya Laboratoriya*, 1955, **21**, (4), 507–508). [In Russian]. Different formulae for determining true strength are considered on the basis of data for a variety of steel test pieces.—S. K.

Polarization-Optical Method of Measuring Stresses in Actual Structural Elements. Z. D. Vishnevetskiĭ. (*Zavodskaya Laboratoriya*, 1955, **21**, (4), 480–482). [In Russian]. Special techniques for using optical-polarization strain-gauges on full-size structural units are outlined. A new design of double polariscope is described.—S. K.

Effect of Microstructure on the Morphology of Fracture. Part II. J. C. Danko, R. D. Stout. (*Welding J.*, 1956, Feb., 77s–81s). It is shown that in the coarse-grained ferrite–pearlite microstructure of 1025 steel, the initiation of cleavage failure occurred at the ferrite grain boundaries and ferrite–pearlite interface. Mechanical twins may also initiate failure. The areas of pearlite had a tendency to arrest fracture since the cleavage behaviour of pearlite appears highly dependent on orientation.—U. E.

Method for Studying the Stability of Residual Stresses during Cyclic Loading. M. M. Kobrin. (*Zavodskaya Laboratoriya*, 1956, **21**, (4), 467–472). [In Russian]. An account is given of a simple method for evaluating the removal of residual stresses by pre-treatment involving bending or torsion. The evaluation is based on the change in length of a smooth test-piece. The results for steel show that comparatively large stresses are required for the removal of residual stresses produced by surface work-hardening. Complete removal occurs only above the endurance limit when the bending and torsion stress-gradient is large; with large specimens (smaller gradient) the treatment is more effective.

Electrical Method of Measuring Deformation during the Torsion Testing of a Metal. N. G. Mikhaĭlichenko. (*Zavodskaya Laboratoriya*, 1955, **21**, (4), 472–475). [In Russian]. A new installation consisting of a testing machine with an elastic load-measuring device and a tensometric apparatus is described by the aid of which torsional deformations can be recorded. The method, based on the measurement of elastic deformations of a rod, is sufficiently accurate and reliable for normal testing and is relatively simple. The record it provides (coordinates torque and angle of twist) is more complete than those of existing installations. A curve obtained for a structural steel test piece 10 mm in diameter is presented.

Method for Determining Shear Modulus. I. N. Ermolov and E. Kh. Ripp. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 726–727). [In Russian]. The application to the determination of shear modulus at high temperatures of a method recently developed for the high-temperature determination of moduli of normal elasticity is described. Results obtained for two steels at temperatures up to 700° C are presented.

The Effect of Microstructure on Notch Toughness—Part III. J. H. Gross, R. D. Stout. (*Welding J.*, 1956, Feb., 72s–76s). The effect of microstructure on notch toughness of a fine-grained plain carbon steel (0·32% C) was studied. It is shown that a higher cooling rate during transformation has a beneficial effect on notch toughness. The spacing of the pearlite is of secondary importance. In ferrite–pearlite aggregates the ferrite grain size is decisive and pearlite of low-carbon content resulting from dilution with ferrite exhibits unusually good notch toughness. Small amounts of untempered martensite markedly reduce notch toughness.—U. E.

The Charpy V-Notch Test Piece for Testing Mild Steel for Welding Purposes. G. Malmberg. (*Jernkontorets Ann.*, 1956, **140**, 2, 87–100). [In Swedish]. Impact-temperature curves were obtained for a series of steels: 8 rimming, 8 semi-killed and 10 killed. It is concluded that a minimum mean value of 3·5 kgm/cm² should be quite suitable as a standard for impact tests on weldable steels, variations in specifications being checked by laying down different test temperatures whilst keeping the impact value constant. A suggestion is made that in any series of test bars, none should exhibit an

impact value at the specified temperature which is less than 2·6 kgm/cm².—G. G. K.

A Method for the Determination of the Total State of Deformation from an X-Ray Photograph.—II. G. Kemmnitz. (*Z. Metallkunde*, 1955, **46**, Sept., 720–721). Formulae are derived for the calculation of total deformation from X-ray photographs.—L. D. H.

Stress Measurements in Cast Iron by the Modified Invariant Method. H. Schlechtweg. (*Giesserei, Technisch-Wissenschaftliche Beihefte*, 1955, May, 801–803). There are three possible methods for stress measurements in cast iron when, instead of Hooke's elastic law in the virgin state, a non-linear law is followed. They are: the stress sum-and-difference method, the invariant method and the modified invariant method. In the first and the last a knowledge of normal strain perpendicular to the surface is not necessary. The necessary formulae for the modified invariant method are developed and used in one practical case, given as an example.—R. J. W.

X-Ray Measurements of Internal Stress, and their Use in Evaluating the Strength of Structures. M. Čermák. (*Hutnické Listy*, 1956, **11**, (1), 21–26). [In Czech]. Formulae for the determination of internal stresses by X-rays, based upon Brandenberg's representation of the theory of elasticity, are derived, and are shown to facilitate the attainment of much higher accuracies than by older methods.—P. F.

The Graphical Processes in Radiographic Strain Measurement. G. Kemmnitz. (*Arch. Eisenhüttenwesen*, 1955, **26**, Aug., 437–443). The author describes diagrammatic methods for the interpretation of *X*-ray strain measurements to give the internal stresses and material constants. The methods are claimed to be of especial value for the practical application of radiological strain measurement.—A. C.

Comparison of Radiographically and Mechanically Measured Strains in Cast Iron. V. Hauk. (*Arch. Eisenhüttenwesen*, 1955, **26**, Aug., 449–453). Following earlier experiments, comparative tests were carried out using three types of grey cast iron with various graphite structures. The different stress-strain diagrams for tensile, compressive, and bending loads are discussed in relation to the effects of the different graphite formations and their variation under stress. Inferences as to the nature of the stressing and straining process are drawn from a comparison of the mechanical and *X*-ray measurements.—A. C.

Characteristics of the Surface Layers and Elastic Constants of 0·43% Carbon Steel Determined by X-Ray Stress Measurement. H. Hendus and C. Wagner. (*Arch. Eisenhüttenwesen*, 1955, **26**, Aug., 455–461). A description is given of radiological tests to determine the elastic stress-strain characteristics and the internal stresses, using test specimens of steel containing 0·16, 0·43 and 0·76% carbon. Experimental and theoretical results are compared and discussed.—A. C.

Industrial Applications of Radiographic Stress Measurement. A. Schaal. (*Arch. Eisenhüttenwessen*, 1955, **26**, Aug., 445–447). After a discussion of the principles involved, a photographic method is described for the rapid determination both of the sense and the magnitude of stresses. Examples are given of the determination of internal stresses, and of the effects of static and dynamic loading on the internal stresses.—A. C.

Residual Stress in Cold-Drawn Steel Tube. I. H. Imai. (*Tetsu to Hagane*, 1956, **42**, Jan., 23–28). [In Japanese]. Methods of measuring residual stress are compared; that based on corrected micrometer measurements of the diameter is better than that using an optical comparator. Specimen length should be 2·0–2·5 × the outside diameter. Distribution diagrams are given for residual circumferential stress in plug-drawn and sunk tubing drawn with dies of different contour.—K. E. J.

The Scale Effect in the Cup Drawing Test. J. F. Wallace. (*J. Iron Steel Inst.*, 1956, **183**, 144–148). [This issue].

Studies on Ball-Bearing Steel. IV. Effect of the Tempering Temperature on the Internal Stress of Ring-Type Test Pieces. M. Ueno and T. Mura. (*Tetsu to Hagane*, 1956, **42**, Jan., 29–34). [In Japanese]. Circumferential and radial stresses were determined for ring-type test pieces after quenching and after tempering at 130, 180, and 200° C, and analysed according to structural changes occurring. (13 references).—K. E. J.

On the Thermal Aspect of Fatigue. A. M. Freudenthal and J. H. Weiner. (*J. Appl. Phys.*, 1956, **27**, Jan., 44–50). The highly localized temperature and associated thermal stress gradients in front of active slip planes which result from the conversion into heat of the work in slip of the resolved shear stress, may be of sufficient severity to account for the initiation of micro-cracks parallel to the slip planes. The effect of thermal characteristics of the metal in fatigue performance is discussed.—E. E. W.

What You Can Do About Metal Fatigue. A. G. Gray. (*Steel*, 1956, **138**, Jan. 16, 68–72). The problem of failure from metal fatigue is considered and suggestions are made for minimizing trouble; there is also a section on fatigue testing.—D. L. C. P.

The Fatigue Resistance of Machine Parts. R. Cazaud. (*Métaux Corrosion–Indust.*, 1956, **31**, Jan., 1–17). The general theories of fatigue are briefly considered. The influence of the shape and metallurgical state on the fatigue of machine parts is discussed with examples. The increase in fatigue resistance by fine polishing of the surface is explained and the fatigue of parts due to corrosion is mentioned.—B. G. B.

Study of Creep of Chrome–Molybdenum Steels Made by Aciéries Electriques d'ARBED at Dommeldange. J. Biren and P. Wagener. (*Rev. Tech. Luxembourg*, 1955, **47**, Oct.-Dec., 205–224). A comprehensive account of an investigation into the creep properties of chrome-molybdenum steels of the type used in power stations is presented. The fundamental principles of creep and creep testing are first discussed. The tests were carried out on specimens having different compositions, but all of the same general type. The influence of heat treatment and composition on creep resistance has been studied. The majority of the test conditions were related to the use of the steel.—B. G. B.

Contribution to the Measurement of the Modulus of Elasticity and Damping of Sintered Materials. R. Palme and W. Scheiber. (*Planseeberichte*, 1955, **3**, Dec., 87–95). The moduli of elasticity of carbon- and alloy sintered steels are measured and results discussed. The apparatus consists of an emitter causing oscillations in the test-bar and an indicator for the amplitudes of the vibrations.—R. P.

Investigation of the Fatigue of Metals by X-ray Scattering. A. Franks and J. Holden. (*Nature*, 1955, **176**, Nov. 26, 1022–1023). Low angle scattering of X-rays have given results of promise in detecting fatigue damage in metals.—B. G. B.

The Alternating Bending Strength of Armco Iron at Various Grain Sizes. H. Hendus and G. Kraus. (*Z. Metallkunde*, 1955, **46**, Sept., 716–720). Experiments on the alternating bending strength of Armco iron at grain sizes between 0·03 and 3·2 mm showed that the strength diminished rapidly with increasing grain size. The effect is due to the occurrence of intercrystalline fatigue cracks; in almost all cases a platelike precipitation parallel to the (101) planes was observed, attributed to the separation of η-carbide.—L. D. H.

Fatigue—What We Do and Don't Know About It. G. R. Gohn. (*S.A.E. J.*, 1955, **63**, Sept., 38–44). The author presents a concise review of the present state of knowledge of the various aspects of metal fatigue. The initiation of fatigue and the shortenings of theory are discussed, followed by an account of other mechanical properties of metals which leads to the conclusion that fatigue bears no relation to any of them. Factors that affect fatigue strength, such as structure, test procedure, and shot peening are also discussed.—P. M. C.

Resistance to Fatigue. I. Bertolini. (*Libreria Editrice Politecnica Cesare Tamburini Milan*, 1952). [In Italian]. The author gives a very comprehensive review of the subject of fatigue in metals. (135 references).—M. D. J. B.

Studies of Fatigued Railway Rails. I. I. Konishi, M. Kawamoto, H. Miki, M. Adachi, B. Kundo, J. Takamura, Y. Niwa, and H. Goto. (*Tech. Rep. Eng. Res. Inst., Kyoto Univ.*, 1955, **5**, Mar., 19–52). Trials with a magnetic flaw detector show that most of the recording curves obtained are due to unevenness in the upper rail surface, and some quantitative relationships may be deduced. The quenching of the steel and "dappled rails" may cause traces. Deformation due to fatigue is one of the causes of unevenness.—K. E. J.

Consideration of the Precision of the Vickers and Rockwell Hardness Measurements. E. Rossow. (*Métaux Corrosion–Indust.*, 1955, **30**, Dec., 476–483). The Vickers measurement is considered to have an accuracy of the order of 5%. Analysis of the sources of error has shown that the personal error of operators is the largest. Elimination of these personal errors leaves a residual error of the order of 0·5 to 2%. Comparison with the Rockwell C technique shows that the latter is more rapid and has superior precision. However, the Vickers value is superior to the Rockwell value in accuracy if both are based on a series of observations.—B. G. B.

Changes in the Hardness of Pure Metals During Heating.

M. G. Lozinskii and S. G. Fedotov. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (4), 80–85). [In Russian]. An apparatus for measuring hardness of metals at temperatures up to 1100° C *in vacuo* is described. Experimental results obtained for aluminium, copper, iron (0·05% C), nickel, cobalt, titanium, molybdenum, and tungsten are given.—V. G.

Studies on the Wetting Effect and the Surface Tension of Solids. The Change in Scratch Hardness of Metals due to Wetting by Liquids. M. Sato. (*Proc. Japan Acad.*, 1955, **31**, Nov., 620–623). The scratch hardness of steel is shown to be decreased by wetting with methanol, glycerine, and distilled water.—B. G. B.

The Influence of Small Amounts of Work Hardening on the Mechanical and Technological Properties of Steel Strip. L. Dainelli and L. Cocciolo. (*Met. Ital.*, 1955, **47**, Nov., 501–504). [In Italian]. This paper studies the influence of small degrees of work hardening (0·5 to 4%) on cold rolled and annealed mild steel strip. The work done on the strip is similar to that done on a skin pass mill. The tests described were carried out on basic open hearth steel with 0·09 C, 0·50 Mn, 0·011 P, 0·038 S, and 0·27 Cu, hot rolled into strip 150 mm wide in thicknesses of 1, 1·5, and 2 mm. Analyses of the results are given in some detail.—M. D. J. B.

Studies on the Brittle Failure of Tankage Steel Plates. F. J. Feely, M. S. Northup, S. R. Kleppe, and M. Gensamer. (*Welding J.*, 1955, **34**, Dec., 596s–606s). Results are reported of tests carried out on tankage steel plates to determine the causes of failure. A practical solution to the tank building problem has been recommended.—U. E.

The Effect of Heat Treatment, Dressing and Ageing on the Cold Brittleness of Rail Steel. G. I. Pogodin-Alekseev and N. S. Artemenko. (*Stal'*, 1955, (5), 455–458). [In Russian]. Impact tests with smooth test pieces indicated that the best heat treatment for reducing cold brittleness was normalization. Normalized test-pieces were subjected to special bending tests, to evaluate the influence of the cold-dressing process by which rails are straightened after final cooling. The bending procedure eliminated the beneficial effects with respect to cold brittleness of normalizing. Finally, a study of the cold-brittleness of the normalized steel before and after dressing and after dressing and artificial ageing showed the influence of ageing to be small.—S. K.

On the Accuracy of the Determination of Wear of Machine Parts Using Radio-Active Indicators. Yu. S. Zaslavskii, G. I. Shor, and F. B. Lebedeva. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (1), 54–59). [In Russian]. The accuracy of the determination of wear of machine parts using radioactivity was investigated on an example of an irradiated piston ring. It was found that an irradiated piston ring has a uniform macro and micro distribution of radioactive atoms throughout the whole mass of the metal and is suitable for quantitative determination of wear.—V. G.

Some Recent Experiments in Friction. E. P. Bowden and E. H. Freitag. (*Nature*, 1955, **176**, Nov. 19, 944–946). The results of friction experiments carried out over a wide range of speeds up to 1000 metres/sec are described. The frictional process at very high speeds is different from that occurring at low speeds.—B. G. B.

Wear of Metals by Sand Erosion. W. A. Stauffer. (*Metal Progress*, 1956, **69**, Jan., 102–107). A description of a machine for testing the resistance of metals to erosion by sand suspended in water is given. This is of great importance in connection with hydraulic turbines. The results of tests carried out are given and agree well with those obtained in practice.

Effect of Precipitation in the Embrittlement Temperature Range of 475° C on Magnetic Properties of Iron–Chrome Alloys. E. Baerlecken and H. Fabritius. (*Stahl u. Eisen*, 1955, **75**, Dec. 29, 1774–1784). Saturation, Curie point, and coercivity were observed for iron–chrome alloys (containing 24–66% Cr) in the embrittlement range. The experimental results are presented and discussed.—A. C.

Electronic Apparatus for the Measurement of Magnetic Susceptibilities. J. Joussot-Dubien, B. Lemanceau, and A. Pacault. (*J. Chim. Phys.*, 1956, **54**, Feb., 198–205). The apparatus, which is compact and simple to use, gives results comparable with those obtained using classical apparatus. The theory is given, and the apparatus described.—T. E. D.

Spontaneous Magnetogalvanism and Magnetization in Some Irreversible Ferronickels. A.-L. Perrier and E. Ascher. (*Compt. Rend.*, 1955, **240**, Mar. 7, 1066–1068). It is normally impossible to vary the spontaneous magnetization of ferromagnetic materials at constant temperature and vice versa. This problem can be overcome by using irreversible ferronickels.—G. E. D.

The Effects of Cold Work Upon the Properties of Permanent Magnet Alloys. T. Mishima, K. Tachikawa, and T. Oya. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 215–219). [In Japanese]. The effects of various degrees of cold working and ageing on mechanical and magnetic properties were determined for Co–Fe–V, Co–Fe–Cr, Fe–Ni–Cr, and Co–Fe–Cr–V. The transformation of γ- to α-phase during cold work is accompanied by a linear increase of saturation induction value, and magnetic anisotropy appears with severe cold work.—K. E. J.

Variation in Fatigue Properties Over Individual Casts of Steel. Part I—Investigation of a Cast of Steel to B.S.970 Specification En.100. E. Ineson, J. Clayton-Cave, and R. J. Taylor. (*J. Iron Steel Inst.*, 1956, **183**, 177–184). [This issue].

The Barkhausen Effect. R. S. Tebble. (*Proc. Phys. Soc.*, **B**, 1955, **68**, Dec. 1, 1017–1032). The domain structure of an iron-like crystal is considered. The only mechanism which will produce discontinuities of the observed size and give the usual hysteresis curve is one in which the movement of a limited section of a 180° domain boundary is delayed by a non-magnetic inclusion of cross-sectional dimensions $1 - 2 \times 10^{-5}$ cm. Hysteresis loss in ferromagnetic materials is best brought about by reducing the number of inclusions within the critical size range.—K. E. J.

Magnetic Domain Structure in Twinned Crystals of Silicon Iron. R. Street and E. O. Hall. (*Proc. Phys. Soc.*, **B**, 1955, **68**, Dec., 1033–1037). The modification of magnetic domain structures on $\{110\}$ surfaces of single crystals of 3·5% Si–Fe by the presence of twin bands is examined by colloid deposition techniques. The structure is determined by the presence of free poles, alternately of opposite sign, on the twin/crystal interface, giving regular domains separated by 180° boundary walls.—K. E. J.

Ferromagnetic Domains in Permanent Magnet Materials. L. F. Bates. (*Research*, 1955, **8**, Dec., 462–472). An account is given of the domain concept and its application to ferromagnetic metals. Tests of theories by the powder pattern technique are described, and applications of the technique to, e.g. Alnico and columinar Alcomax, are explained.—K. E. J.

The Effect of Heat Treatment on the Hysteresis Loss in Hot-Rolled Transformer Sheet. F. Lihl and P. Zemsch. (*Arch. Eisenhüttenwesen*, 1955, **26**, Sept., 535–540). The authors describe investigations of the variation in hysteresis losses with treatment temperature and time. A steel containing 4·3% Si and 0·25% Al was used, and magnetic and metallographic examinations made of the variously annealed specimens. The results of the tests are discussed in relation to the Néel theory.—A. C.

A Short Review of Ultrasonic Non-Destructive Testing of Iron and Steel Products. W. Demicheli. (*Ing. Mecc.*, 1955, **4**, Oct., 9–16). [In Italian]. The author describes briefly the principal methods of ultrasonic non-destructive testing and reviews the main applications in industry, namely: production control, acceptance tests, and the field testing of pieces. Present and future possibilities of ultrasonic testing are discussed.—M. D. J. B.

The Effect of Deoxidation Practice and Hot Work Reduction on the Occurrence of Magnaflux Indications in E4340 Type Steel. A. F. Sprankle. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 269–295). The author has studied the effects on magnaflux test indications of the amount and type of hot work carried out on test ingots from two heats of Ni–Cr–Mo aircraft steel, one deoxidized with calcium–silicon and the other with ferrosilicon. The calcium–silicon deoxidant is shown to give considerably lower magnaflux indications, and the effects of hot working are tabulated and discussed.—G. F.

Xeroradiography. P. J. Farmer. (*Aircraft Prod.*, 1956, **18**, Jan., 8–12). The equipment for rapidly producing radiographs by an electrostatic method is described. Improved contrast and greater sensitivity is possible than with photographic film.—T. E. D.

Comparison between the Continuous and Impulse Wave Methods of Testing Materials. A. de Sterke. (*Metalen*, 1956, **11**, Feb. 29, 77–89). [In Dutch]. This article is based on a paper read in Dec. 1953 at Rotterdam replying to a question raised before a meeting of the Roentgen Technisch Dienst (X-Ray Technical Service). The author makes a comparison

between these methods of detecting hidden faults in materials and welds. A table appears indicating their relative advantages and disadvantages. To conclude, there is a lengthy discussion, with the author's replies to the points raised.

X-Ray Spectral Analysis with Counting Tube Appliances. G. Lang. (*Z. Metallkunde*, 1955, **46**, Sept., 616–620). Modern developments in X-ray emission and absorption analysis are described, with particular reference to the use of counters.

Intensification of the X-Ray Image in Industrial Radiology. A. Nemet and W. F. Cox. (*Proc. Inst. Elect. Eng.*, Preprint U1881, 1955, July). The application of an X-ray image intensifier tube, originally designed for medical diagnosis, to industrial radiology, is described.—L. D. H.

Directions of Zero Strain in the Unstressed State, and Their Significance in Radiographic Stress Measurement and Structural Testing. F. Binder and E. Macherauch. (*Arch. Eisenhüttenwesen*, 1955, **26**, Sept., 541–545). The equation for strain-free directions is evolved. The axially symmetric, the unidirectionally stressed, and the shear-stressed cases are dealt with in particular, though other stress cases are briefly considered. It is shown that the strain-free directions exist for all cases. In radiographic work it is possible to select the direction of the incident rays so that the normal to one of the crystal lattice plane assemblies is in line with one of these directions.—A. C.

Performance of a 15 mV Betatron in the Radiography of Steel. H. Möller, W. Grimm, and H. Weeber. (*Arch. Eisenhüttenwesen*, 1955, **26**, Oct., 603–609). Tests were carried out on the Siemens–Reiniger 15 mV betatron in order to compare its performance with that of the Brown–Boveri 31 mV betatron. The results are claimed to show that the 15 mV betatron is a useful and trouble-free means for the testing of materials, having an advantage over the 31 mV betatron in its smaller weight.—A. C.

Visible Penetrant Dye Method Finds Defects in Jet Parts Faster at Less Cost. (*Western Metals*, 1954, **12**, Dec., 66–67). The uses and applications of Met-L-Chek Flaw-Findr, a penetrant dye for crack detection, are described. Flaws and cracks are revealed by soaking the parts in a bath of the penetrant dye, followed by rinsing and "development" by a spirit developer spray.—P. M. C.

Radiography of Metals. (*Metal Progress*, 1955, **68**, Aug. 15, 185–194). Factors affecting the efficacy of this non-destructive technique for detecting discontinuities in metals are discussed in detail.—B. G. B.

Electronic "Private Eyes" Guard Against Structural Flaws in Jet Components. A. S. Billings. (*Western Metals*, 1954, **12**, Oct., 63–65). A general account is given of the methods of inspection and their fields of application at the Ryan Aeronautical Co., California. X-radiography, fluorescent, and dye penetrants, magnetic particle techniques, and spectroscopy are dealt with.—P. M. C.

Industrial X-Ray. (*Process Control*, 1955, **2**, Apr., 132–134). Some aspects of industrial X-ray equipment are reviewed, a few typical examples being described and illustrated.—L. D. H.

Application of the Rheo-electric Analogue to the Problems of Industrial Research. P. Germain. (*Rev. Soc. Roy. Belge Ing. Indust.*, **1955**, Dec., 479–493). The use of this technique for solving the Laplace equation is described. Examples of the application of the technique to heat transfer calculations in coke ovens is explained.—B. G. B.

Graphical-Analytical Treatment of Dilatometric Curves. M. M. Levitan. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 712–716). [In Russian]. An attempt is made to develop a generalized form of a graphical-analytical method of treating differential dilatometric curves. The treatment enables quantitative determinations of mean coefficients of linear expansion and phase-changes in alloys during heating and cooling to be made.—S. K.

Influence of Addition of Nickel on the Thermal Expansion, Rigidity Modulus and its Temperature Coefficient of the Alloys of Cobalt, Iron and Chromium, Especially of Co-Elinvar. II. Additions of 30 and 40% Nickel. H. Masumoto, H. Saito, Y. Sugai. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1955, **7-A**, Dec., 533–540). The influence of 30 and 40% additions of nickel on the thermal expansion in the range 10–50° C, on the rigidity modulus at 20° C, and the temperature coefficient of the modulus of alloys of cobalt, iron, and chromium, was investigated, and are reported in detail. Nickel-bearing Co-elinvar had better mechanical properties than the plain ternary alloys.—J. G. W.

Studies on Mechanical Properties at Elevated Temperature of Timken 16–25–6. I. T. Hasegawa, O. Ochiai, and J. Ino. (*Tetsu to Hagane*, 1956, **42**, Jan., 44–49). [In Japanese]. The creep resistance and yield strength at 650° C were increased by long-time solution treatment before age-hardening, as the precipitate was more finely divided. The effects of long- and short-time solution treatment on ductility, etc., were investigated in various tensile and other tests.—K. E. J.

Room- and Elevated-Temperature Mechanical Properties of AISI Type 414 and Type 431 Stainless Steels. E. J. Dulis, S. J. Parker and P. W. Marshall. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 41). Results are given for tests on the tensile properties at room temperature and in the range 370–600° C and for creep and creep-rupture properties in the range 480°–650° C of the following stainless steels:—

12% Cr, 2% Ni, 0·015% N; 12% Cr, 2% Ni, 0·124% N;
16% Cr, 2% Ni, 0·010% N; 16% Cr, 2% Ni, 0·063% N.

Keyhole notch transition temperatures were also determined for the two lower nitrogen content steels.—E. E. W.

Experimental Superheater for Steam at 2000 p.s.i. and 1250° F.—Progress Report after 12,000 Hours of Operation. F. Eberle, F. G. Ely and J. A. Dillon. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, 665–677). Results are given of an examination of tube sections removed from an experimental superheater after 6950 hr of operation at 1250° F. Most of the tubing alloys used were of the austenitic stainless steel type and no evidence of serious impairment of essential properties could be detected in any of them. Some of the weld metals, however, particularly 18/12 Mo and 17/14 Cu–Mo, suffered considerable impact embrittlement.—D. H.

Carbon and Nitrogen in Iron Alloys: Solubilities under Various Conditions. (*Iron Coal Trades Rev.*, 1955, **171**, Dec. 30, 1593–1597). A summary is given of information, presented at the Autumn Meeting of the Iron and Steel Institute, concerning the thermodynamics of carbon dissolved in liquid iron alloys and the solubility of nitrogen in solid iron.—G. F.

High Nitrogen Steels: New Stainless Family. D. J. Carney. (*Steel*, 1955, **137**, Nov. 7, 138–744). Development of a new nickel-free stainless steel by U.S. Steel Corp. is described. Many experiments were made adjusting chromium, nickel, and nitrogen contents, and compositions were found where high nitrogen contents could be held, to maintain the stability of austenite up to 2300° F. Properties and applications are indicated.—D. L. C. P.

The Effects of Nb, V, Ti and N on the Properties of Ni–Cr–Co (20–15–15%) Series Heat-Resisting Steel for Gas Turbines. S. Koshiba and T. Kimo. (*Tetsu to Hagane*, 1956, **42**, Jan., 39–43). [In Japanese]. Forgability and oxidation resistance were improved by Nb additions, while N improved tensile strength at high temperatures. As to ageing hardness after solution treatment at 1200° C, and creep limit, the untreated specimens were superior.—K. E. J.

The Effect of Non-Metallic Inclusions and Molybdenum on the Mechanical Strength of 13% Cr Steel. K. Ono and R. Sasaki. (*Tetsu to Hagane*, 1955, **41**, Dec., 1258–1264). [In Japanese]. Tests were made with steel containing 0·13–0·20% of C and 12·69–13·13% of Cr, with varying inclusions, and with Mo contents up to 1·06%. Inclusions do not affect tensile strength, but reduce impact strength at high temperatures and rotating-bending fatigue strength. The tensile and fatigue strengths of the steel decrease with temperature, but the endurance ratio increases. Mo increases the tensile and fatigue strengths at high temperatures, the latter being doubled by increasing the Mo content from 0 to 1·06%. (11 references).—K. E. J.

Boron in Case-Hardening and Strengthened Steels. K. Bungardt and E. Kunze. (*Härterei-Tech. Mitt.*, 1953, **8**, (2), 21–33). The influence of small and large boron additions is discussed with particular reference to hardness. Relevant curves are shown.—R. P.

Causes and Cures of Some Blemishes and Faults in Railway-Wheel Tyres. T. Myslivec and S. Hořejš. (*Hutnické Listy*, 1956, **11**, (1), 1–9). [In Czech]. Methods of production and their relation to faults are reviewed. The author's experiments indicate that (*a*) segregation is not a cause, but may accentuate fracture in the presence of internal stresses; (*b*) surface blowholes and cracks can be prevented by adding the correct amount of aluminium to the melt, i.e. 0·1–0·2 kg/ton; (*c*) internal flaking can be prevented by regulated cooling of the tyres, or possibly by anti-flaking anneals of

the tyres or the pear-shaped ingots; (*d*) water quenching is preferable to oil quenching; (*e*) aluminium additions to the ladle result in impact-strength improvement throughout the tyre; (*f*) water quenching, followed by tempering improves the wear-resistance.—P. F.

Working Experience of a Works Laboratory at a Machine-Construction Works. O. L. Bendryshev. (*Zavodskaya Laboratoriya*, 1955, **21**, (2), 249–251). [In Russian]. The organization of a works laboratory including metallurgical, technological, mechanical, chemical, spectral, corrosion, and experimental sections is described.—S. K.

METALLOGRAPHY

The Bonding Conditions in Metallic Phases. U. Dehlinger, H. Schenk and W. Weser. (*Z. Metallkunde*, 1955, **46**, Sept., 647–650). It is argued that bonding in metallic phases is a general case of a Bloch method, of which homopolar and heteropolar bonding represent rare boundary cases. A number of examples are discussed.—L. D. H.

The Binding Energy of Nitrogen in a Dislocation. W. R. Thomas and G. M. Leak. (*Proc. Phys. Soc.*, **B**, 1955, **68**, Dec. 1, 1001–1007). The solubility of interstitially-dissolved nitrogen has been measured in annealed and cold-worked α-iron by the internal friction technique. In annealed iron, the heat of solution of N, in equilibrium with a pptd. nitride, is 0·26 eV per atom. In cold-worked iron, the equilibrium is between N atoms in free solution and bound in dislocation sites; the binding energy is 0·75–0·8 eV per atom. (12 references).—K. E. J.

A New Method of Measuring the Last Debye-Scherrer Lines with the Tube Counter. R. Berthold and V. Gerold. (*Z. Metallkunde*, 1955, **46**, Sept., 599–601). A counting tube with an annular diaphragm is described, lines being measured by the alteration in distance of the preparation.—L. D. H.

Dislocation Densities in Some Annealed and Cold-Worked Metals from Measurements on the X-ray Debye-Scherrer Spectrum. G. K. Williamson and R. E. Smallman. (*Phil. Mag.*, 1956, 8th Series, **1**, Jan., 34–46). Two basic equations are derived for deducing the dislocation density in powdered materials from the particle size and strain breadth measured from the Debye-Scherrer spectrum. Results are given for several metals, and the effects of purity, treatment, etc., are considered; results for iron include dislocation densities for the annealed and cold-worked metal, and estimates of the range for heavily cold-worked metal. (12 references).

Determination of Diffusion Coefficients of Elements in Ferrite with Aid of Radioactive Isotopes. V. M. Golikov and V. T. Borisov. (*Zavodskaya Laboratoriya*, 1955, **21**, (7), 824–827). [In Russian]. The theory of diffusion-coefficient determination in ferrite with the aid of radioactive isotopes is considered and ways of allowing for processes occurring in the deposited radioactive layer are described. The technique was used for studying the self-diffusion of iron in an iron–chromium alloy. Values of the diffusion coefficient were obtained at annealing temperatures of 650–850° C and gave an activated energy higher than for pure iron.—S. K.

Condition of Boron in Alpha Iron. W. R. Thomas and G. M. Leak. (*Nature*, 1955, **176**, July 2, 29–31). Measurements have been made on iron wires containing 0·05% boron using the internal friction technique. The results suggest that boron is in interstitial solution in α iron.—B. G. B.

Microstructural Observation of the Decarburized Zone of Alloy Steels. A. A. Popov and M. S. Mikhalev. (*Zavodskaya Laboratoriya*, 1955, **21**, (4), 447–449). [In Russian]. A new method for enabling the decarburized zone of low- and high-carbon alloy steels to be observed by examination of microstructures is based upon the finding that the lower the carbon content of decomposing austenite the more rapid and complete is the intermediate transformation. The small specimen is soaked at the second-stage temperature for the duration of the incubation period for the initial austenite-content and is then rapidly cooled. The decarburized zones are indicated by the presence of large quantities of intermediate-transition products.—S. K.

Study of the Homogeneity of Alloys and Mobility Along Grain Boundaries with the Aid of Radioactive Isotopes. S. Z. Bokshteĭn, T. I. Gudkova, S. T. Kishkin and L. M. Moroz. (*Zavodskaya Laboratoriya*, 1955, **21**, (4), 423–432). [In Russian]. The theory of the autoradiographic method as applied to the study of the distribution of elements in alloys is discussed, and suitable methods are described. Results obtained for carbon in cast steel (0·33% C), for tin in iron and for various elements in nickel are illustrated and examined. During the study of the kinetics of element redistribution the possibility was noted of increased heterogeneity as a result of diffusional annealing. The mobility of components was found to be considerably greater in deformed than in cast alloys. Diffusion inside a crystal and along grain boundaries can be studied photometrically.—S. K.

CORROSION

Sodium Sulfate in Gas Turbines. E. L. Simons, G. F. Browning and H. A. Liebhafsky. (*Corrosion*, 1955, **11**, Dec., 17–26). At about 950° C and under reducing conditions, stainless steel (25% Cr, 20% Ni) can be rapidly destroyed by sodium sulphate in the fuel ash. Experimental evidence is given and the mechanism of the attack discussed.—J. F. S.

Corrosion Control on Offshore Drilling and Producing Equipment. C. J. Fritts. (*Corrosion*, 1955, **11**, Nov., 25–30). Recommendations are made for protecting steel piling in and above the sea based on experience of an oil company. Vinyl paint is used in the atmospheric zone. In the most corrosive environment, the splash zone, a choice may be made between 'Gunite,' Monel or plastic jacketing, porcelain enamelling, sheet Neoprene, flame-sprayed polyethylene, metallizing and plastic tapes or vinyl mastic over vinyl paint. Cathodic protection with magnesium anodes is preferred underwater.

A Note on the Value of Ammonia Treatment for Tank and Casting Annulus Corrosion by Hydrogen Sulphide. W. F. Rogers. (*Corrosion*, 1955, **11**, Nov., 42–44). The injection of anhydrous ammonia into the vapour space of tanks storing crude oil did not reduce the corrosion rate unless the steel was free of iron sulphide corrosion products. In these circumstances protection was afforded for about six months but then, in the presence of hydrogen sulphide, the corrosion rate reverted to the normal value.—J. F. S.

Use of Ammonia to Prevent Casing Corrosion. H. E. Greenwell, R. Loncaric and H. G. Byars. (*Corrosion*, 1955, **11**, Nov., 45–50). The theoretical considerations which suggest that ammonia will prevent corrosion of internal casing of oil wells are reviewed. When the pH value exceeded 6, ammonia prevented further corrosion of panels first corroded in air-free, saturated hydrogen sulphide solution. Details are given of service tests using a high pressure lubricator to inject the the ammonia. The ammonia is believed to have penetrated below the zone of most corrosion and the economics of the method are favourable.—J. F. S.

Electrochemical Studies of the Hydrogen Sulphide Corrosion Mechanism. S. P. Ewing. (*Corrosion*, 1955, **11**, Nov., 51–55). The anodic and cathodic reactions in the corrosion of iron by hydrogen sulphide brines in the absence of oxygen are stated and supported by experimental evidence. The corrosion potential depends only on the hydrogen sulphide activity of the solution and the partial pressure of molecular hydrogen. A thin copper coating has conferred protection in a laboratory test. The effect of oxygen is mentioned briefly. Reference is made to the similarity between carbon dioxide and hydrogen sulphide.—J. F. S.

Electrode Potentials. G. W. Akimov. (*Corrosion*, 1955, **11**, Nov., 31–40, Dec., 27–46). Characteristics of reversible and irreversible electrode potentials are defined with reference to their ionic patterns. Polarization of a metal surface is related to the limits of ionic exchange. The theory of electrode potentials is considered mathematically and in terms of dipole surface layers. Factors which affect the electrode potentials include the chemical nature of the metal, its surface state, absorbed atoms and molecules particularly O_2 and H_2, mechanical deformation and stress, chemical nature and concentration of the environment, temperature, velocity of the solution, and time. The relative magnitude of these factors is considered and particular reference is made to solutions containing oxidizers and chlorides.—J. F. S.

Non-Uniform Anodic Dissolution; Water-Line Attack. A. M. Peers. (*Trans. Faraday Soc.*, 1955, **51**, Dec., 1748–1754). Preferred dissolution of mild steel anodes in the vicinity of the meniscus has been found to occur under certain conditions in oxygen-free sodium chloride solutions. It is concluded that solutions which support localized dissolution are those in which the concentration changes at the anode surface which accompany the passage of current tend to reduce the anodic over potential, dissolution taking place

preferentially at the meniscus zone where the concentration changes are magnified by hindered diffusion.—B. G. B.

Electrochemistry of Stainless Steel in Sulphuric Acid. G. H. Cartledge. (*Nature*, 1956, **177**, Jan. 28, 181–182). The electrode potential during the transformation of an air-stable oxide film to the surface-state that exists in dilute, aerated sulphuric acid at temperatures between 25° and 90° C has been continuously recorded. The results obtained are discussed in relation to those obtained by other workers.

Feeding Chemicals to Boilers in Steel Mill Power Plants. D. E. Noll. *Blast Furn. Steel Plant*, 1956, **44**, Jan., 82–86). Techniques developed for the addition of phosphates and sodium sulphite into boiler water are described.—B. G. B.

Tentative Standard Method for the Assessment of the Rust-Preventing Characteristics of Hard Film and Soft Film Temporary Corrosion Preventives. (*J. Inst. Petroleum*, 1956, **42**, Feb., 50–54). Results leading to a proposed standard method of testing the efficacy of hard and soft petroleum type coatings in inhibiting the corrosion of steel specimens are described in detail. The tests are carried out under conditions of high humidity and with SO_2 in the air.—B. G. B.

Corrosion of Metals in Alkaline Solutions. On the Contact Corrosion of Dissimilar Metals. I. Mild Steel–Aluminium Alloy. H. Endo, N. Ohtani and S. Shimodaira. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 211–214). [In Japanese]. Experiments were made in Na_2CO_3 solutions at 30°. The loss in wt. of mild steel decreases at pH > 8, owing to cathodic protection. The loss in wt. of aluminium is accelerated by contact with mild steel; when [OH′] is large, the rate is determined by the reaction $H^{\cdot} \rightarrow H$, and when small by the reaction $Al(OH)_3 + NaOH \rightarrow NaAlO_2$.—K. E. J.

The Exterior and Interior Protection of Underground Steel Conduits. T. Sunnen. (*Rev. Tech. Luxembourg.*, 1955, **47**, Apr.–June, 97–101). A short account of the design and cost of cathodic systems of protection for underground steel pipes is given.—B. G. B.

Cathodic Protection. F. Ritter. (*Werkstoffe Korrosion*, 1955, **6**, Nov., 523–527). A general factual exposition of methods and procedure for the cathodic protection of buried or immersed metals, based mainly on American publications.—J. C. H.

The Effect of Alloying Elements in Iron on Hydrogen Overvoltage and Corrosion Rate in Acid Environments. M. Stern. (*J. Electrochem. Soc.*, 1955, **102**, Dec., 663–668). The effect of 0·1% Cu, Si, and Mn respectively, 0·02% S and P respectively on the hydrogen overvoltage and corrosion rate of iron in 0·1M citric acid, 0·1M malic acid and 4% NaCl solution was studied. Sulphur, phosphorus and carbon reduced corrosion resistance but copper and manganese mitigated the effect of sulphur. The results are interpreted on the basis of the hydrogen overvoltage measurements.

Mathematical Studies on Galvanic Corrosion. IV. Influence of Electrolyte Thickness on the Potential and Current Distributions over Coplanar Electrodes Using Polarization Parameters. J. T. Waber and Bertha Fagan. (*J. Electrochem. Soc.*, 1956, **103**, Jan., 64–72). Detailed numerical evaluation of Fourier series were made to elucidate the opposing influences of liquid depth and the polarization parameter in a 'microscopic' galvanic cell. It is shown that in thin films corrosion attack is confined largely to the immediate vicinity of the anode-cathode boundaries and that this region tends to enlarge.—A. D. H.

Electrochemical Corrosion in Nearly Neutral Liquids. U. R. Evans. (*J. Electrochem. Soc.*, 1956, **103**, Jan., 73–85). The author reviews his fundamental researches on corrosion of metals in nearly neutral liquids. The influence of variations in the physical state of the surface and chemical composition of the liquid, measurements of corrosion current and pitting are discussed.—A. D. H.

Corrosion of Condenser Tubes. G. Zamorani. (*Calore*, 1955, **26**, Oct., 438–446). [In Italian]. The author examines the principal causes of corrosion in condenser tubes, the various types of corrosion and the preventive measures which can be taken to overcome its worst effects.—M. D. J. B.

ANALYSIS

A Ferricyanide–ceriometric Determination of Vanadium. B. Suseela. (*Anal. Chim. Acta*, 1955, **13**, Dec., 543–545). A volumetric method is described in which ceric sulphate is used instead of permanganate to titrate the ferrocyanide formed by the oxidation of vanadyl ions with alkaline ferricyanide.—E. E. W.

A Method for the Simultaneous Quantitative Analysis of Carbon and Sulphur in Steel and Cast Iron. F. L. Racine. (*Gen. Motors Eng. J.*, 1955, **2**, July–Aug., 20–22). The same sample can be used for both C and S determinations, and considerably greater accuracy is claimed for this method. The entire process is completed in four minutes, and a novel feature of the method is the use of an electronic titrimeter.

Direct-Reading Analysis with the Medium Quartz Spectrograph. D. J. Webb. (*Hilger J.*, 1955, **2**, Nov., 19–24). A direct reading attachment, containing 11 photomultiplier tubes, for the Hilger medium quartz spectrograph is described. 10 elements can be determined.—B. G. B.

Spectroanalytical Installation with Voltage Control Mechanism. K. Möhl, E. Schael, and J. Bruch. (*Arch. Eisenhüttenwesen*, 1955, **26**, Nov., 669–673). The authors describe an installation and control equipment that has been developed. The control system is claimed to be simple, and voltage to be free of fluctuation.—A. C.

Trace Analysis Using Radioactive Isotopes. W. Herr. (*Arch. Eisenhüttenwesen*, 1955, **26**, Sept., 523–526). The fundamentals, general advantages, and sensitivity of the method are discussed, and application to the determination of phosphorus in iron is described. Possible sources of error are reviewed.—A. C.

Potentiometric Determination of Vanadium in High-Chrome Steels. J. Bünger. (*Arch. Eisenhüttenwesen*, 1955, **26**, Nov., 675–678). The author refers to the lack of a visual method of volumetric analysis, and to attempts at potentiometric determination. He discusses the disturbing influence of unidentified substances, and gives methods of neutralizing their effects. Suitable experimental procedure is described.

Use of Mathematical Statistics for Studying the Reproducibility of the Chemical Analysis of Non-Alloy Steels. S. A. Genshaft, V. V. Nalimov and V. G. Pines. (*Zavodskaya Laboratoriya*, 1955, **21**, (7), 877–880). [In Russian]. Results of chemical determinations of carbon, sulphur and phosphorus in steel are subjected to statistical analysis and reproducibilities at various concentration levels are discussed.

Colorimetry, Its Application to the Chemical Analysis of Cast Irons. V. Kuhn. (*Fonderie*, 1955, June, 4560–4562). The principles of colorimetric analysis are reviewed and its application to the analysis of cast irons is very briefly considered.—B. C. W.

A Method for the Colorimetric Determination of Free Cyanide in Electrolytic Baths. G. Heilmann. (*Metalloberfläche*, 1955, **9**, Dec., 208A–209A).

The Use of the Vacuum Heating Method for the Determination of Hydrogen in Iron. E. I. Egorov. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 659–661). [In Russian]. In the investigation described the effects of sampling procedures and other factors on the results of vacuum-heating determinations of hydrogen in cast iron were studied.—S. K.

Determination of Hydrogen in Cast Iron. Yu. A. Klyachko, A. G. Atlasov and Yu. D. Labut'ev. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 651–658). [In Russian]. A special apparatus for analysing gases from the vacuum fusion of iron is described and the effects of sampling methods on the results of hydrogen determination are considered. Vacuum fusion was found to be the most reliable method for hydrogen determination, best results being obtained when the metal sample is rapidly cooled without wetting in a water-cooled mould. Hydrogen was not evolved during storage at room temperature of basic- and foundry-iron samples cooled in water and in air.—S. K.

The Aluminium Reduction Method for the Determination of Oxygen in Steel Used in the Laboratories of The Steel Company of Wales Ltd. (Newport Division). J. E. Wells. (*J. Iron Steel Inst.*, 1956, **183**, 184–186. [This issue].

Determination of Boric Acid in Nickel-Plating Electrolytes. I. M. Yurist and P. G. Shakhova. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 539). [In Russian]. An improved procedure for finding the end point in the determination of boric acid in nickel-plating baths by titration in the presence of precipitated nickel is described.—S. K.

Copper Salicylaldoxime and its Use in the Heterometric Microdetermination of Copper in the Presence of Foreign Metals. M. Bobtelsky and E. Jungreis. (*Anal. Chim. Acta*, 1955, **13**, Nov., 449–454). Clear end points were obtained in the presence of iron (~ 95%) only if the solution contained citrate as a masking agent.—E. E. W.

Resorcylaldoxime as an Organic Reagent. A. K. Mukherjee.

(*Anal. Chim. Acta*, 1955, **13**, Oct., 334–339). Methods are described for the use of resorcylaldoxime for the determination, in the presence of other ions, of copper (pH of solution 1·4) and of nickel (pH 4·2–6·55).—E. E. W.

Oxidations with Alkaline Permanganate using Monovalent Thallium for the Back Titration. I. M. Issa and R. M. Issa. (*Anal. Chim. Acta*, 1955, **13**, Oct., 323–327). Tests using monovalent thallium instead of formic acid for back-titrating alkaline permanganate have proved successful in the estimation of Cr^{3+}.—E. E. W.

Titrimetric Determination of Aluminium in Steel. C. Elliott and J. W. Robinson. (*Anal. Chim. Acta*, 1955, **13**, Oct., 309–312). This method is based on an acid–base titration of Al^{3+} first in the absence and then in the presence of fluoride. The iron is first separated by using dichlorodiethyl ether.—E. E. W.

Residual Analysis of Pig Iron and Cast Iron. I. Electrolysis. A. Wittmoser and H. Bockshammer. (*Arch. Eisenhüttenwesen*, 1955, **26**, June, 319–328). Owing to the high carbon content, there are great difficulties in the application to pig iron and cast iron of the method developed by Klinger and Koch for the residual analysis of steels. To avoid these difficulties, the attempt was made to electrolyse the whole of a sample instead of the outer surface only. A technique was developed, and its application to the electrolysis of cast iron alloys is described.—A. C.

Residual Analysis of Pig Iron and Cast Iron. II. Separation. A. Wittmoser and W.-D. Gras. (*Arch. Eisenhüttenwesen*, 1955, **26**, July, 379–388). Existing methods of separation require considerable time and apparatus, and suffer from the destruction of important constituents such as cementite, and difficulties in the fusion of graphite. The authors describe an improved method, using the simplest equipment, that has been developed for the separation of cementite, graphite, oxides, etc., from isolated residues. Cementite is magnetically separated, while graphite is separated from oxides by a flotation process. The method is stated to have wide application.—A. C.

Spectro-Analytical Determination of Carbon in Steels. M. Török and G. Szikora. (*Acta Techn.*, 1955, **13**, (1–2), 165–185). [In German]. Higher accuracies are shown to be attainable if the spark is struck in an atmosphere of hydrogen rather than in air. The gas enters through a central bore in the copper anti-cathode, the latter being enveloped by a quartz jacket. The design of the electrodes, the experimental procedure, and the accessories used are described in detail.—P. F.

The Separation and Direct Determination of Titanium, Iron and Aluminium by Means of Cupferron and Complexone—III. Z. Večeřa and B. Bieber. (*Práce Ceskoslovenského Výzkumu Slévárenského* (*Appendix to Slévárenství*, 1955, **3**, (11)). [In Czech].

Optical Procedure for the Determination of Trace Elements by Concentration. H. Specker. (*Arch. Eisenhüttenwesen*, 1955, **26**, May, 267–270). After a short review of spectroscopic analysis, the necessity of concentration of trace elements is indicated. Methods of concentration and separation are given, making use mainly of organic reagents.

Nephelometric Determination of Copper. W. Denck and C. Mahr. (*Arch. Eisenhüttenwesen*, 1955, **26**, May, 271–274). Reference is made to recent literature, and the optical use of turbidity for quantitative analysis is illustrated. The suitability of the method and the effects of experimental conditions and procedure are examined.—A. C.

Photometric Determination of Molybdenum in Steel. J. Bünger. (*Arch. Eisenhüttenwesen*, 1955, **26**, June, 333–335). A review of the literature is given. The use of thiocyanate and the reduction of the test-solution with tin(II)–chloride is referred to. The author describes a method that has been developed to enable the easy and rapid determination of molybdenum content.—A. C.

Determination of Nickel, Chromium and Molybdenum, Using the Spekker Absorptiometer. J. Winning and S. Miller. (*Metallurgia*, 1956, **53**, Jan., 50–52). Details are given of an improved method for determining these elements using inexpensive chemicals and avoiding the use of perchloric acid or silver nitrate. A considerable increase in speed of analysis also claimed.—B. G. B.

Electrolytic Analysis: The Mercury Cathode Apparatus as Applied to Ferrous Materials. (*Iron Steel*, 1956, **29**, Feb., 61–62). The development of the B.T.L. Magnetic Mercury Cathode electrolytic analysis apparatus is described, and operating details are given. The scope and limitations of the method in ferrous analysis are outlined.—G. F.

Co-precipitation of Cobalt with Nickel Dimethylglyoxime. G. K. Schweitzer and B. L. McDowell. (*Anal. Chim. Acta*, 1956, **14**, 2, February, 115–120). Experiments have shown that minimum co-precipitation is obtained by the slow addition of ammonia to an acid solution containing salts of the two metals and dimethylglyoxine at 25° C followed by a 30-minute digestion.—E. E. W.

Separation of Calcium and Aluminium from Iron by an Ion Exchange Method. O. Samuelson and B. Sjöberg. (*Anal. Chim. Acta*, 1956, **14**, 2, February, 121–125). Using an anion exchanger in the citrate form calcium passes into the effluent while iron and aluminium are taken up in the column; the latter is then eluted using concentrated hydrochloric acid.—E. E. W.

Bromometric Determination of Vanadium^{V} by Hydrazine. G. S. Deshmukh and M. G. Bapat. (*Anal. Chim. Acta*, 1956, **14**, 3, March, 225–227). Accurate results have been obtained over a wide range by reducing vanadium V with hydrazine in a high concentration of hydrochloric acid; the excess hydrazine is back titrated against standard potassium bromate, using the dead-stop end-point procedure. Hydrazine is preferentially oxidised by bromate in the presence of vanadium^{IV}.—E. E. W.

Gravimetric Method for Determining Tungsten in Concentrates and Alloy Steels. V. V. Stepin and E. V. Silaeva. (*Zavodskaya Laboratoriya*, 1955, **21**, (2), 149–151). [In Russian]. The use of pyramidone for the gravimetric determination of tungsten is described.—S. K.

The Use of 4-Amino-4′-Chlorodiphenyl Hydrochloride for the Determination of Sulphur in Coal. H. C. Wilkinson. (*Analyst*, 1956, **81**, Jan., 9–11). The bomb combustion method is used. Results of analyses of 12 coals show the mean difference in sulphur contents determined using this reagent and by the Eschka method is 0·03% S. Analysis time is reduced by 30 mins.—T. E. D.

Chromatographic Separation and Analysis of Gas Mixtures. J. Janák. (*Paliva*, 1955, **35**, (12), 357–361). [In Czech]. Foreign and Czechoslovak developments in gas chromatography up to 1954 are reviewed, and the theoretical principles discussed. An instrument produced commercially in Czechoslovakia, suitable for the analysis of coke-oven gases and other gas mixtures, is described.—P. F.

On the Determination of Oxygen and Combustible Material in Coal. H. Romováčková and F. M. Kessler. (*Paliva*, 1955, **35**, (12), 351–356). [In Czech]. Oxygen was determined directly by the reduction of pyrolytic products on a layer of carbon, and their subsequent re-oxydation to carbon dioxide. The latter is then determined gravimetrically. The method was tested successfully in the case of a number of coals. A new, rapid, method for calculating the oxygen content of coals from the data is developed. The method is shown to be applicable also to the evaluation of the content of other elements, and to be superior to those in current use.—P. F.

Note on Gas Analysis Absorbents for Carbon Monoxide. Y. Okinaka and T. Kato. (*Technol. Rep. Tôhoku Univ.*, 1953, **18**, (1), 12–15). The absorption efficiency of six different cuprous copper solutions, commonly used in carbon monoxide analyses, was measured. None of the solutions was found efficient and it is concluded that two or three absorption pipettes should be used in succession, with a freshly prepared solution in the last, and frequent checks of the partial pressure of CO over this solution need to be made.

Determination of Sulphur in Coal and Coke by the Sheffield High Temperature Method. R. A. Mott and H. C. Wilkinson. (*Fuel*, 1956, **35**, Jan., 6–18). The development of this combustion method of determining sulphur is described. An account of recent work on factors influencing the accuracy of the method is given. These factors include the rate of flow of oxygen, rate of pushing into the hot zone, and the design of absorber.—B. G. B.

Methods for Detecting and Determining Carbon Monoxide. R. L. Beatty. (*U.S. Bur. Mines, Bull. No.* 557, 1955). A detailed review of this subject is presented, together with a comprehensive bibliography citing 175 references.—B. G. B.

Spectrochemical Analysis of Clays and Fireclays. G. Hartleif and H. Kornfeld. (*Arch. Eisenhüttenwesen*, 1955, **26**, June, 329–332). The authors discuss the advantages and disadvantages of three different methods, and the possibilities

of error under certain conditions. The analytical methods used by the authors are described, and their results compared with those given by wet-chemical methods.—A. C.

Some Applications of Polarography to Slag Analysis. Ch. Killens. (*Silicates Indust.*, 1955, **20,** Dec., 477–478). [In French]. The methods of polarography are briefly reviewed, and the elements in slags which can be determined by this method are listed. Fe, Ti, Cd, Zn, and possibly Na and K, can be determined even if present in concentrations of 1% or less.—P. F.

Estimation of Silica. A. K. Majumdar and S. Banerjee. (*Anal. Chim. Acta*, 1955, **13,** Nov., 424–426). Under suitable pH conditions, silica has been quantitatively precipitated as the silicomolybdic salts of either 5,6-benzoquinaldine or 8-hydroxyquinaldine. The salts are stable and non-hygroscopic and may be weighed either directly after drying at 110°–150° C or after igniting to silicomolybdic anhydride at 550° C with free access to air.—E. E. W.

Use of the Isotope C^{14} for Studying the Diffusion of Carbon in Metals. P. L. Gruzin, Yu. A. Polikarpov and M. A. Shumilov. (*Zavodskaya Laboratoriya*, 1955, **21,** (4), 417–423). [In Russian]. In the investigation described the diffusion of carbon in α- and γ-iron, iron with 2·1% Si, and in nickel was studied. The specimen was case-hardened using a mixture containing radioactive carbon and diffusion was followed by measuring radioactivities at various depths after soaking under various conditions of temperature and time. The values of the diffusion coefficients and activation energies obtained agreed well with published results. The diffusion coefficients in austenite and nickel were very similar, and the use in elucidating the behaviour of carbon in iron–nickel alloys is indicated.—S. K.

INDUSTRIAL USES AND APPLICATIONS

Thomas Steel for Rails. M. Srinivasan. (*Railway Gaz.*, 1956, **104,** Jan., 27, 98–100). The satisfactory use of basic bessemer steel for rails in many parts of the world is discussed. Criticisms of basic bessemer steel for this purpose are considered.—B. G. B.

What We Know About Cam and Tappet Materials Design and Lubrication. (*S.A.E.J.*, 1955, **63,** Sept., 56–65). Cam and tappet face failure in automobile engines can be classified into three categories: gradual and smooth wear, scuffing, and spalling or flaking through fatigue. Recent experiences and findings of General Motors', Ford's, and Chrysler's engineers are reviewed at some length with special reference to: (1) the most suitable combinations of materials, (2) the shape of contacting surfaces, and (3) the choice of lubricants.—P. M. C.

High-Strength Low-Alloy Steels. C. M. Parker. (*S.A.E.J.*, 1955, **63,** July, 50–54). A general appraisal is made of the properties and applications of high-strength low-alloy steels having a total alloy content of 2–3%. The author stresses the usefulness of these steels in motor vehicle construction, particularly because of their toughness, corrosion resistance, ease of fabrication and superior strength to weight ratio as compared with plain carbon steels.—P. M. C.

Study of 7% and 8% Chromium Creep-Resisting Steels for use in Steam Power Plant. M. G. Gemmill, H. Hughes, J. D. Murray, F. B. Pickering, and K. W. Andrews. (*J. Iron Steel Inst.*, 1956, **183,** 122–143). [This issue].

All-Metal Honeycomb Sandwich Structures. J. V. Long and G. D. Cremer. (*S.A.E.J.*, 1955, **63,** Apr., 52–55). The honeycomb sandwich has extraordinarily high strength to weight ratio, excellent stiffness, good thermal and acoustical insulation properties, excellent fatigue resistance and high damping ability. Foil thin ribbons joined in honeycomb pattern comprise the core which is sandwiched between metal facings or skins by brazing. The composite structure when made of alloy steels or heat resisting alloys is designed to withstand the high stresses and temperatures encountered in supersonic flight—both inside and outside the aircraft.

Chrome-Steel Springs Endure Heat Best. F. P. Zimmerli and W. P. Wood. (*S.A.E.J.*, 1954, **62,** Nov., 35–38). Results are given of fatigue and relaxation tests on springs in the temperature range −75 to 650° F. Seven types of material were tested. With the exception of high-speed steel and 18/8 stainless, chrome-silicon steel springs gave the lowest load loss or set in both static and dynamic tests in the temperature range from atmospheric to 450° F. Shot peening did not improve the performance.—P. M. C.

The Selection and Application of Stainless Steel in the Chemical Process Industries. (*Metal Progress*, 1955, **68,** Aug. 15, 37–49). The applications discussed are limited to chemical solutions that carbon and other metals cheaper than stainless steel do not resist satisfactorily. General corrosion, intergranular corrosion, stress corrosion cracking and pitting can cause failure of stainless steels. Minor variations in environment have a marked effect on the service life of stainless steel. Design and fabrication practices can also greatly influence performance.—B. G. B.

Scientific Points of Comparison Between the Various Methods of Bending Sheet Metal. O. Kienzle. (*Microtecnic*, 1955, **9,** (4), 177–184). The seven main methods of bending sheet metal over straight edges are outlined. A device for bending free from shear stresses is described, with its applications to the determination of bending moments. The geometry and precision of the bending operation are discussed.

HISTORICAL

Metallurgical Treatises of the 16th to 18th Centuries. B. Gille. (*Techn. Civil.*, 1955, **4,** Nov.–Dec., 181–186). Metallurgical works of Rüblein von Kalbe, Agricola, Vanoccio Biringuccio, Dud Dudley, Alvaro Alonso Barba, Réaumur, Etienne-Jean Bouchu and Gaspard de Courtivron and of many others are outlined.—T. E. D.

Tubal Cain. R. J. Forbes. (*Metalen*, 1956, **11,** Mar. 15, 101–108). [In Dutch]. Beginning with Tubal Cain as "the first artificer in metals," the author traces historically the development of metallurgy and siderurgy throughout the ages amongst the primitive peoples in various parts of the world.

MISCELLANEOUS

Towards Efficient Experimentation. H. C. Hamaker. (*Metalen*, 1955, **10,** Dec. 15, 489–497). [In Dutch]. The author advocates the proper analysis of experimental data on a statistical basis to cope with the large random fluctuations, the need for large numbers of observations and the numerous variables encountered in modern industrial conditions. Seven practical examples are given.—F. R. H.

Isotopes and Metal Engineering. G. G. M. Carr-Harris. (*Canad. Metals*, 1955, **18,** Apr., 26–32; May 5, 22–26). The application of radioactive isotopes in the design and production of metal products is discussed.

The Scattering of μ-Mesons in Lead and Iron. J. L. Lloyd and A. W. Wolfendale. (*Proc. Phys. Soc.*, **A**, 1955, **68,** Nov. 1, 1045–1065). Cloud-chamber experiments, using Pb and Fe plates, were made to determine the dependence of the scattering of μ-mesons on momentum, sign, and at. no. The results agree with theories, particularly Molière's (point nucleus). (29 references).—K. E. J.

Monte Carlo Methods in Heavy Industry. H. G. Jones and A. M. Lee. (*Operational Res. Quart.*, 1955, **6,** Sept., 108–116). The statistical study of batch processes is discussed, particular reference being made to the prevention of 'bunching' of O.H. furnaces.—B. G. B.

Use of Radioactive Isotopes in Metallurgy. Yu. V. Kornev. (*Zavodskaya Laboratoriya*, 1955, **21,** (1), 42–55). [In Russian]. This is a survey of recent work outside the U.S.S.R. in which radioactive isotopes were used in metallurgical research and testing.—S. K.

Statistical Methods in Metallurgy. U. R. Evans. (*Metallurgia*, 1955, **52,** Sept., 107–111). A short account of the application of statistical principles to metallurgical research is given.—B. G. B.

The Ayrshire Dockyard. (*Lithgow J.*, 1955, **2,** Autumn Issue, 10–14; Winter Issue, 12–17). The historical account of the activities of this dockyard is presented. Pressed metal products are at present being manufactured.—B. G. B.

The Part Played by France in Metallurgy. P. G. Bastien. (*Usine Nouvelle*, 1955, **11,** June 23, 14–15; June 30, 15–16). Past and present French contributions to progress in iron and steelmaking, the metallurgy of aluminium, magnesium, light alloys, copper, and the white metals, and control and testing equipment are briefly described.—T. E. D.

Continuous Casting and the Use of Oxygen in Steel Production. (*Tenth Scientific Conference*). F. Rapatz. (*Bol. Assoc. Brasil Met.*, 1955, **11,** Jan., 31–44, 45–57, 111–133, 135–152). [In Portuguese]. This group of articles includes two papers given by Dr. F. Rapatz and reports of two discussion groups held at the 10th conference of the Brazilian Society of Metals. The papers describe the continuous casting of steel and the

use of oxygen in the iron and steel industry. One discussion group was also concerned with the use of oxygen, the other with the use of Brazilian coal in the iron and steel industry.

Metallurgical Uses of Radioactive Isotopes. U. Been. (*Tidsskr. Kjemi, Bergvesen Met.*, 1955, **15**, (6), 104–106). [In Norwegian]. Sections discuss the use of isotopes for measuring diffusion rates, self-diffusion, vapour pressures of metals, and for studying microstructures, friction, sulphur in coke, and air passage rates through blast-furnace burdens. Two examples illustrate their use in determining the efficiency of electrode mixing machines and a study of cement burning times using a scintillation counter.—G. G. K.

Quality Control in Mass Production. E. Schmiegelow. (*Bol. Assoc. Brasil. Met.*, 1954, **10**, Oct., 335–345). [In Portuguese]. The author takes the mass production of piston rings as an example and, after discussing the principal features of their manufacture, shows how statistical control assures quality and homogeneity in the product.—P. S.

BOOK NOTICES

DEARDEN, JOHN. "*Iron and Steel To-day.*" Second Edition. 8vo. pp. 272, illustrated. Oxford, 1956: Oxford University Press. (Price 12*s.* 6*d.*).

The new edition of this book incorporates references to important new techniques, such as steel moulding, continuous casting of steel, the manufacture of spheroidal-graphite iron and of low-nitrogen Bessemer steel, and the use of the oxygen lance in arc furnaces. The various data have been revised, the description of the types of steel has been rewritten, and a chapter has been added indicating post-war development in the industry. There is also, in the Appendix, useful matter on commercial aspects of the trade and the location of the industry in Britain.

In all, the book represents a lucid, balanced, and up-to-date survey of the manufacture of iron and steel products and of their characteristics. It is pleasing to read, well illustrated, and, considering the overall attractiveness of the presentation, the price remains very reasonable. The book can be recommended to various technical people who require a good general picture of the industry, similarly to the ordinary person with an interest in such matters. More particularly, the volume can be regarded as very useful reading matter for those actually engaged in the industry who are studying for the iron and steel operatives' examinations, or who merely want a general understanding of their work.

Only two minor misprints were noted, but the error of describing the High Level Bridge at Newcastle as a wrought-iron bridge has been repeated from the earlier edition. It is, in fact, a cast-iron bridge.—A. R.BAILEY.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH. "*Heat Bibliography*, 1948–1952." Prepared by Heat Division, Mechanical Engineering Research Laboratory, East Kilbride. 8vo, pp. 414. Sept., 1954.

This bibliography, which has been recently made available to a wider public than the Heat Division of M.E.R.L., for which it was originally prepared, contains about 8000 references to the study of heat; its generation, transmission and utilization are all covered, together with the effects of heat on, and on heat of, innumerable other physical phenomena and properties. Each of the 46 sections is arranged in alphabetical order of authors, but there is no other indexing arrangement beyond a very full table of contents. Only references are given, but, as in so many papers in pure science, the titles are usually a sufficient guide to the contents. In spite of a number of trivial errors of spelling, this bibliography should be of much use to physicists and engineers alike.—J. P. S.

WILSON, W. KER. "*Practical Solution of Torsional Vibration Problems.*" Volume I. "*Frequency Calculations.*" Third edition. 8vo, pp. xxxii + 704. Illustrated. London, 1956: Chapman & Hall, Ltd. (Price 105*s.*)

Ever since its first appearance twenty-one years ago this book has been looked upon as a standard reference work on the subject. In this third edition the author has not only brought it up to date by incorporating recently published data and newer methods of treatment, but has also taken the opportunity of completely revising its layout to facilitate reference to any particular aspect. The number of chapters has been increased by sub-division, and the two volumes have been made more self-contained, the present Volume I dealing only with calculations of torsional vibration frequencies, leaving amplitude and stress calculations to Volume II.

The emphasis of the book is on the word "practical." All the essential theory of torsionally vibrating systems, and systems in which torsional and other vibrations are coupled, is given; but theory only deals with the behaviour of model systems comprising concentrated, or uniformly distributed, masses connected by shafts of known stiffness. The particular usefulness of this book lies in the help it gives the engineer in translating his practical assembly of machine elements into the appropriate model, and in carrying out his frequency calculations by systematic tabular methods. The methods used are liberally illustrated by worked examples.

As would be expected from the author's background, many of the examples deal with aero-engine/airscrew or marine-engine/propeller systems, but the problems with which the steelworks engineer is faced are in general likely to be simpler than these, and the methods described are of quite general application. Geared systems receive particular attention and those involving other transmission elements such as belts and chains are adequately dealt with.

The book is well indexed and contains a classified bibliography.—H. R. MILLS.

KUBASCHEWSKI, O., and J. A. CATTERALL. "*Thermochemical Data of Alloys.*" (Metal Physics and Physical Metallurgy Series, No. 3). 8vo, pp. 200. Illustrated. London and New York, 1956: Pergamon Press. (Price 45*s.*).

Compared with the number of alloy systems which have formed the bases of constitutional studies, the number of parallel thermodynamic studies is small. Nevertheless, Kubaschewski and Catterall have, by an exhaustive review of the literature, been able to give at least some relevant thermodynamic data on over two hundred binary and some forty ternary metallic systems. From the viewpoint of the reader who is principally concerned with steels and alloys of iron, there is much to interest him in this book. Information is given on over thirty systems involving iron, and thermodynamic data obtained from studies of systems of the transition elements with the non-metallic elements oxygen, carbon, nitrogen, sulphur, and phosphorus form a large part of the book.

The treatment of the subject matter parallels closely that in "*Metallurgical Thermochemistry*," by Kubaschewski and Evans—that is to say, the book is essentially for reference purposes. The experimental methods used for the determination of thermodynamic quantities have not been given in detail, since these have already been adequately discussed in "*Metallurgical Thermochemistry.*" The absence of this information in no way means that, as a reference book, it is not self-contained. Nevertheless, in an introduction of only thirteen pages, the authors have given a survey of the methods, both experimental and mathematical, of arriving at thermodynamic data which is excellent in its insight and balance. Throughout the rest of the book the approach and the discussion of the results are always severely practical, and no attempt has been made to discuss the theoretical implications of the data. This does not imply any criticism, since it is not the authors' intention to discuss theoretical aspects of the thermochemistry of metallic systems, and it is highly unlikely that much could be gained at the present time by such a discussion except for the cases of a few simple and isolated systems.

In this book the authors have been obliged to give thermodynamic data not only for stoichiometric compounds but also for solid solutions, and they have chosen, for the most part, to give these data in tabular rather than diagrammatic form. Wherever possible they have given the partial entropy and heat of formation of one component and the equivalent integral functions at a series of alloy concentrations, and have also added the volume change on formation whenever this quantity can be estimated with acceptable accuracy. By presenting the data in this form, the integral free energy and the partial thermody-

namic functions of the other component of a binary system can be readily computed.

Throughout the book the authors have made an excellent job of critically appraising the various, frequently conflicting, results of different workers, and Dr. Kubaschewski's lifelong devotion to this subject is apparent in the expert manner in which the assessment of the experimental results has been carried out.—A. D. McQuillan.

NEW PUBLICATIONS

Akimow, G. W. "*Korrosion und Verschleiss von Stähle*," und ihre Bekampfung in Dampferzeugungsanlagen sowie in Maschinen- und Fahrzeugbau. Übersetzung aus dem Russischen von Heinz Frohn. Deutsche Redaktion: F.-C. Althof. 8vo, pp. 160. Illustrated. Berlin, 1956: VEB Verlag Technik.(Price DM. 16.60).

British Standards Institution. A.173 : 1956. "100° *Countersunk Head Steel Bolts* (*Unified Threads*) *for Aircraft*." Folio, pp. 13. London, 1956: The Institution. (Price 6*s*.).

British Standards Institution. A.174 : 1956. "100° *Countersunk Head Corrosion-Resisting Steel Bolts* (*Unified Threads*), *for Aircraft*." Folio, pp. 12. London, 1956: The Institution. (Price 6*s*.).

British Standards Institution. S.500 : 1956. "*Inspection and Testing Procedure for Steel Sheets and Strips*." Folio, pp. 22. London, 1956: The Institution. (Price 7*s*. 6*d*.).

British Standards Institution. S.510 : 1956 (replacing 3S.3). "28 *Ton Carbon Steel Sheets and Strips*." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.511 : 1956 (replacing S.84). "*Deep Drawing Carbon Steel Sheets and Strips*." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.512 (replacing 3S.20). "*Tinned Steel Sheets and Strips*." Folio, pp. 4. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.513 : 1956 (replacing D.T.D. 187A). "*Spring Steel Strips*." Folio, pp. 2. London, 1956 : The Institution. (Price 2*s*.).

British Standards Institution. S.514 : 1956 (replacing D.T.D. 124A). "50 *Ton Carbon-Manganese Steel Sheets and Strips* (40 *Ton* 0·1% *Proof Stress*)." Folio, pp. 3. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.515 : 1956. "30 *Ton Carbon-Manganese Steel Sheets and Strips* (*Softened*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.516 : 1956 (replacing D.T.D. 137A). "60 *Ton Carbon-Manganese Steel Sheets and Strips* (50 *Ton* 0·1% *Proof Stress*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.517 : 1956 (replacing D.T.D. 138A). "75 *Ton Carbon-Manganese Steel Sheets and Strips* (65 *Ton* 0·1% *Proof Stress*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.518 : 1956. "50 *Ton Chromium-Molybdenum Steel Sheets and Strips* (40 *Ton* 0·1% *Proof Stress*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.519 : 1956. "75 *Ton Chromium-Molybdenum Steel Sheets and Strips* (65 *Ton* 0·1% *Proof Stress*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.520 : 1956 (replacing D.T.D. 166B). "*Cold-rolled Chromium-Nickel Steel Sheets and Strips* (*Corrosion-resisting*) (40 *Ton* 0·1% *Proof Stress*)." Folio, pp. 2. London, 1956 : The Institution. (Price 2*s*.).

British Standards Institution. S.521 : 1956 (replacing D.T.D.171 and in part D.T.D.571). "*Chromium-Nickel Steel Sheets and Strips* (*Corrosion-resisting*) (13 *Ton* 0·1% *Proof Stress*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.522 : 1956. "23/14 *Chromium-Nickel Steel Sheets and Strips* (*Heat-resisting*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. S.523 : 1956 (replacing D.T.D. 493). "23/18 *Chromium-Nickel Steel Sheets and Strips* (*Heat-resisting*)." Folio, pp. 2. London, 1956: The Institution. (Price 2*s*.).

British Standards Institution. B.S. 2762 : 1956. "*Notch Ductile Steel for Bridges and General Building Construction* (*Suitable for Welding*)." 8vo, pp. 14. London: The Institution. (Price 3*s*.).

Calvo Rodes, R. "*El Acero su Elección y Delección*." La. 8vo., pp. xv + 441. Illustrated. Madrid. (No date): Editorial Dossat. (Price 225 pes.).

Davies, A. C. "*The Science and Practice of Welding*." Fourth edition. 8vo, pp. 524. Illustrated. London, 1956: Cambridge University Press. (Price 18*s*.).

Department of Scientific and Industrial Research. "*Automation*." A report on the technical trends and their impact on management and labour. 8vo, pp. viii + 106. Illustrated. London, 1956: H.M. Stationery Office. (Price 6*s*.).

Espe, W. "*Kovar*." Pp. 84. Füssen, 1956. C. F. Winter'sche Verlagshandlung. (Price DM. 6.40).

Institution of Mining and Metallurgy. "*Mineral Resources Policy*" Proceedings of a Symposium held by the Institution of Mining and Metallurgy on 22nd September, 1955, in the Lecture Hall of the Royal Society of Arts, 6, John Adam Street, London, W.C.2. 8vo, pp. x + 146. London, 1956: The Institution. (Price 10*s*. 6*d*.).

International Union of Theoretical and Applied Mechanics. "*Colloquium on Fatigue, Stockholm, May*, 1955. *Proceedings*." Ed. Waleddi Weibull *et al*. 8vo, pp. xi + 339. Illustrated. Berlin, 1956: Springer-Verlag. (Price DM. 46.50).

Iron and Steel Board and British Iron and Steel Federation. "*Annual Statistics*, 1955." 4to, pp. vii + 151. London, 1956: The Statistics Department. (Price 7*s*. 6*d*.).

Iron and Steel Institute. "*Atlas of Isothermal Transformation Diagrams of B.S. En Steels*." Second edition. Special Report No. 56. 4to, vi + 157. London, 1956: The Institute. (Price 37*s*. 6*d*.).

Kloth, E. "*Untersuchen über die Ausbreitung kurzer Schallimpulse bei der Materialprüfung mit Ultraschall*." (Forschungsberichte des Wirtschafts-u. Verkehrsministeriums Nordrhein-Westfalen), 216. 4to, pp. 79. Köln, 1956: Westdeutscher Verlag. (Price DM. 19.40).

Peierls, R. E. "*Quantum Theory of Solids*." 8vo, pp. viii + 229. Oxford, 1955: Clarendon Press. (Price 30*s*.).

Pironneau, Y. "*Contribution à l'Etude de la Deformation des Métaux par Chocs Répétés*"' La. 8vo, pp. iv + 84. Illustrated. Paris, 1955: Dunod. (Price 4650 fr.).

United Nations. "*The European Steel Market in* 1955." (E/ECE/239; E/ECE/Steel/106). June, 1956. 4to, pp. vi + 107 + 18. Geneva, 1956: Sales Section European Office of the United Nations. (Price 5*s*. 6*d*.).

United Nations. "*Steel and Its Alternatives*." 4to, pp. ii + 75 + 15. (Prepared by the Secretariat of the Economic Commission for Europe. E/ECE/258; E/ECE/Steel/107). Geneva, 1956: Sales Section, European office of United Nations. (Price 4*s*. 6*d*.).

Vaupel, Otto. "*Bild-Atlas fur Zerstörungsfreie Material prüfung*." Berlin, 1955: Verlag Bild und Forschung Ernst Höppner. (Price DM. 110.–).

"*Warmfeste und korrosionsbeständige Sinterwerkstoffe*." Vorträge gehalten auf dem 2. Plansee Seminar "De Re Metallica," 19. bis. 23. Juni, 1955, Reutte/Tyrol. Herausgegeben von F. Benesovsky, Leiter der Versuchsanstalt Metallwerk Plansee Ges.m.b.H., Reutte/Tyrol. 8vo, pp. viii + 472. Illustrated. Wien, 1956: Springer-Verlag.

Wever, F., A. Rose and W. Strassburg. "*Härtbarkeit und Umwandlungsverhalten der Stähle*." Forschungsberichte des Wirtschafts- und Verkehrsministeriums, Nordrhein-Westfalen. 4to, pp. 33. Köln, 1955: Westdeutscher Verlag. (Price DM. 10.70).

Yarwood, J. "*High Vacuum Technique*." Third edition revised. 8vo, pp. vii + 208. London: Chapman and Hall. (Price 25*s*.).

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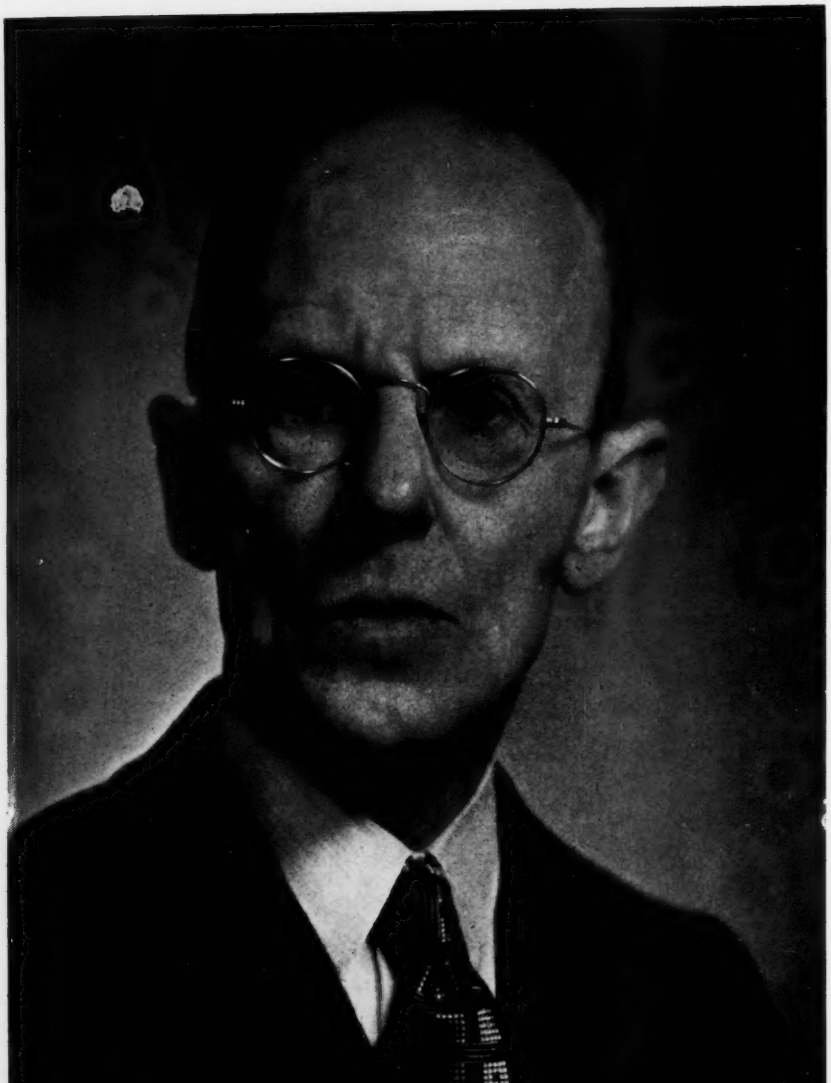

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